IJE TRANSACTIONS A: Basics Vol. 31, No. 4, (April 2018) 679-683

International Journal of Engineering

Journal Homepage: www.ije.ir

TECHNICAL NOTE

Determining of Geotechnical Domain Based on Joint Density and Fault Orientation at Batu Hijau Mine,West Sumbawa-Indonesia

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PAPER INFO

Paper history:
Received 14 October 2017
Received in revised form 02 January 2018
Accepted 04 January 2018

Keywords:
Batu Hijau Mine
Geotechnical Domain
Geotechnical Mapping

ABSTRACT

The research area is located at Batu Hijau Mine – PT Amman Mineral Nusa Tenggara, administratively located at the southwestern of Sumbawa, West Nusa Tenggara Province – Indonesia. The research area is controlled by tectonism in accordance to close with the active tectonic plate at southern part of this island. The presence of the active tectonic regime causes of the rich deposit of ore mineralization and intensive of geological structure in this region. The study was focused on how to develop geotechnical domain which is an important aspect for developing of open pit mine design. The data collecting methods are obtaining by the window and scanline geotechnical mapping in line with excavation stage to execute pit slope design. The research result shows that the geological information is very useful to determine the geotechnical domain. It can be used for guidance on developing pit slope design parameter in open pit mining, and other geotechnical purpose such as defining probability of failure, slope movement guidance, and risk assessment.

***doi**: 10.5829/ije.2018.31.04a.21*

1. INTRODUCTION

The Batu Hijau Mine is one of the biggest copper-gold mine in Indonesia which operated by PT Amman Mineral Nusa Tenggara (PTAMNT). The mine site is located at the southwestern part of the Sumbawa Island, West Nusa Tenggara Province – Indonesia. Based on the geological and geotechnical perspective, the Batu Hijau Mine area is very unique because all of the geological aspect are significantly impacted to the ore deposit condition and pit wall instability event.

The above conditions may be strongly influenced by the subduction zone from the active tectonic plates which located in the southwestern of the study area. Garwin [1] describes the Sumbawa Island lies at the major structural discontinuity in the Sunda-Banda arc, which is characterized by a reversal in polarity of recent volcanism by the intersection of northeasterly and northwesterly oriented arc-transverse tectonic lineaments (Figure 1).

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Scan-line mapping is one of the common methods to obtain geotechnical information to assess pit wall performance and stability. However, the geotechnical information is not only useful for the purpose of slope stability, but, it can be used for another purpose. This study was focused on verifying the impact of the geological structure into the ore-grade distribution at Batu Hijau Mine area as one of the Au-Cu porphyry ore deposit type in Indonesia.

Figure 1. Map showing the tectonic element at the Batu Hijau district on the Sumbawa Island (Modified from Garwin)

Please cite this article as: Y. Adriansyah, Z. Zakaria, D. Muslim, F. Hirnawan, Determining of Geotechnical Domain Based on Joint Density and Fault Orientation at Batu Hijau Mine,West Sumbawa-Indonesia,International Journal of Engineering (IJE),IJE TRANSACTIONS A: Basics Vol. 31, No. 4, (April 2018) 679-683

Geological information is one of the fundamental controls on supporting developing of pit slope design. According to Dearman [2], the characteristic data that need to be collected for engineering geological requirement has to be assembled for the following aspect: lithology, structure, and fault. In addition, there are important aspects of geological information that need to be understood such as description of lithological units, presence of characteristics of fracture, presence of micro structure (fault), and orientation of variation of in situ stresses [3].

2. METHOD

2. 1. Mapping of Joint Density The density of joint was obtained from the geotechnical mapping data which is taken from the outcrop along the bench, hauling ramp, slope-break where geological features exposed on the face above the broken rock [4], and other area that still possible to be mapped by considering to the safety requirement.

2. 2. Structural Model Structural model was generated from the surface and sub surface data. The geotechnical scan line mapping was conducted to obtain the surface data, meanwhile the sub surface data of geological structure was obtained from the oriented geotechnical drilling. Both types of data will be used for constructing the structural model which was conducted into 2 steps that are; surface and sub-surface interpretation (Figure 2).

The surface interpretation was generated from the scan line geotechnical mapping on the exposed pit wall that recorded field information about any structure appearances. The data was interpreted and modeled on the 2D mode based on the azimuth and other fault parameter. Furthermore, the subsurface interpretation was conducted based on the structural geology data from the oriented geotechnical drilling. As a result, a 3D wire framing of structural model was constructed and generated. The process was conducted by using MineSight®.

In term of the size of structural geology in Batu Hijau Mine, the faults are categorized into 2 types namely; major fault and intermediate fault. For geotechnical purpose, all these faults are continuously reviewed and updated based on the new available data that exposed on the wall.

2. 3. LITHOLOGY Generally, the lithology at Batu Hijau Mine can be classified into Volcanic, Diorite and Tonalite (Figure 3). Volcanic rock is the oldest and dominates rock composition at the research area. At the north-eastern part, these rocks are intruded by quartz diorite and continued with a series of Porphyry intrusion Tonalite breaking through the contact zone between Andesite and diorite.

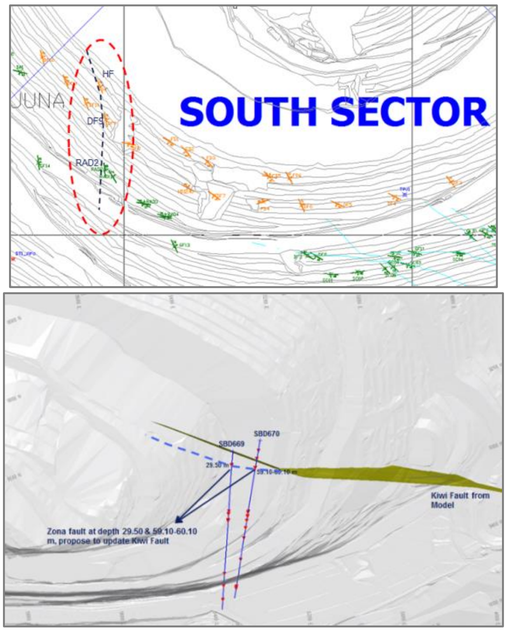

Figure 2. Surface interpretation using scan-line geotechnical mapping and subsurface interpretation from oriented geotechnical drilling data

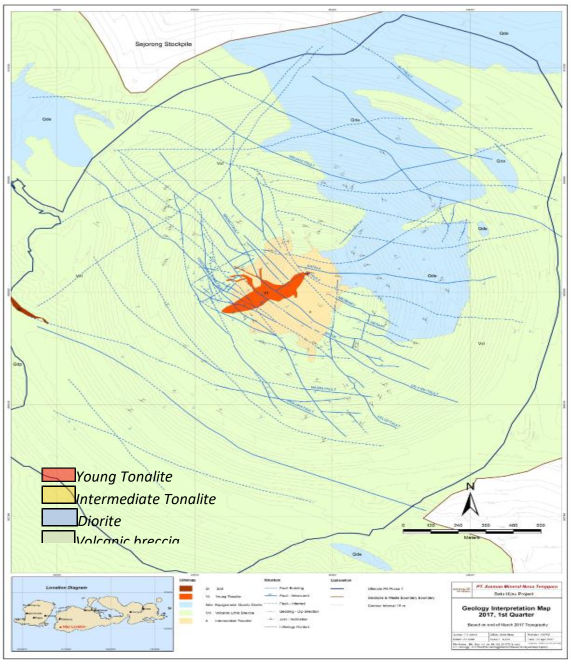

Figure 3. Lithology map showing rock type distribution at Batu Hijau Mine (Modify from Q1 Mine Geology Compilation Map, 2017)

Most of the mineralization process associated with the initial intrusion Tonalite rocks (Old-intermediate Tonalite) which is characterized by the presence of quartz veins intensively, whereas Tonalite end intrusion (Young Tonalite) tend to be associated with mineralization [5].

3. RESULT AND DISCUSSION

3. 1. Distribution of Joint Density Joint information is one of the important aspect that need to be determined early in the design process, this information may have to be based solely on borehole core and associated geophysical testing [6]. Joint density mapping was conducted over the Batu Hijau Mine where the location point can be safely accessed on the bench, ramps and geotechnical slope break.

The area of interest is focused on elevation below 195 mRL to the pit bottom. The total of 236 joint density locations were mapped and covers on the three type of lithology namely Volcanic, Diorite and Tonalite. For further geotechnical assessment, each joint density mapping result were plotted and processed using GEM4D software.

Based on the statistical approach from the histogram distribution, the joint density (JD) at the research area was classified into 4 groups, namely:

1. $JD < 15/m^2$
2. $15/m^2 < JD < 25/m^2$
3. $25/m^2 < JD < 35/m^2$
4. $JD > 35/m^2$

The joint density mapping showed that the high joint density ($JD>35/m^2$) is located and concentrated on the lower north wall and east wall of pit bottom. In addition, the high joint density can also be observed on the middle slope of northwest wall and a localized area in the middle slope of northeast wall. Meanwhile, the joint density in the southwest to north wall of pit bottom is dominantly can be categorized as medium to low.

In the upper slope of east to west wall dominantly has a joint density value ranging from 15 to 25. On the other hand, the upper slope of north to east wall the joint density value is very varied ranging from 15 to 35. The distribution of joint density can be seen on the Figure 4.

3. 2. Fault Orientation The continuous work has been conducted to review and updated the fault model, both for major and intermediate fault. Currently, there are more than 40 major faults and 38 intermediate faults have been generated.

In the research area, the geological structure classification is based on the characteristic and orientation itself, the faults can be divided into six groups or categories. The following Table 1 is the detailed summary of the fault grouping at the research area; meanwhile the map can be seen in the Figure 5.

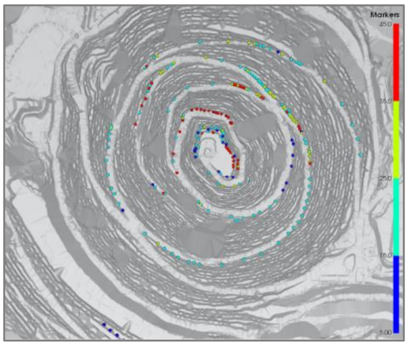

Figure 4. Map showing distribution of joint density. The color indicates the value of joint density

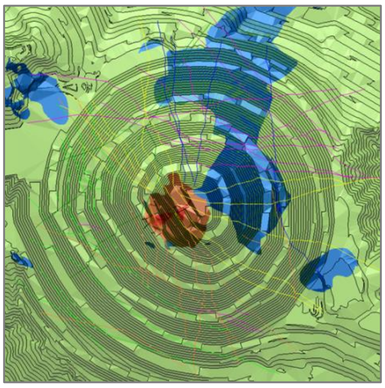

Figure 5. Map showing fault distribution on the pit slope design. The dashed color showed the location of the fault grouping

TABLE 1. Fault grouping at Batu Hijau Mine

Fault Group	Trending	Dipping	Location	Fault Name
Group 1	East – West	Moderate to steep (45° – 70°); dipping to South	North and Northeast wall	Ferry, Ijen, Ronni, Kerinci, Ciremai, North, & Yuli.
Group 2	Northwest – Southeast	Steep (>70°); Dipping to Southwest	North and East wall	Bromo, Merapi, Katim, Katala and ES intermedi-ate fault series. This area was defined as “fault corridor”.
Group 3	Northwest – Southeast	Moderate to Steep (45° – 70°); Dipping to Northeast	South, Southwest and Wall	Tongoloka Puna, Tambora, Kelimutu, Perigi, Arjuna and SW intermediate fault series
Group 4	Northwest– Southeast	Moderate (±45°)Dipping to Southwest	Southwest and West wall	Tongoloka South, Tongoloka Beru, Uka-uka, Nagin, Kawi
Group 5	North	Steep (>70); Dipping to West	North wall	Charly, NS_3, NS_1, NS_2
Group 6	Northeast	Moderate to steep (45° – 70°); Dipping to Southeast	Northwest wall	Sinabung, Kelud, Katala Splays

3. 3. Geotechnical Domain Most of multiple bench scale failures at Batu Hijau were structurally controlled by major and intermediate faults, joint sets and rock fabric. Since the joint density is one of the structural geology characteristics/properties, therefore assessing joint density is an important stage on geotechnical study of the pit slope design. As a result, the joint density distribution can be used as basic information for constructing a structural geotechnical domain. Human and Jupp [7] mentioned that the joint/fracture frequency is one of the main input for 3D wireframes modeling and define geotechnical domain.

The structural geotechnical domain were interpreted and modelled based on joint density distribution combined and supported by structural model that consider potential of failure type. The summary description of each structural geotechnical domain can be seen in the Table 2 and presented in Figure 6.

TABLE 2. Characteristic of structural geotechnical domain

Geotech Domain	Joint density group(/m^2)	Fault Grouping	Potential Failure Type
1	15>JD> 25	Group 2	Wedge Failure
2	25>JD> 35 and JD>35	Group 2 and 6	Wedge Failure
3	25>JD> 35 and 15>JD> 25	Group 1 and 5	Planar Failure
4	15>JD> 25	Group 1 and 5	Wedge and Planar Failure
5	15>JD> 25	Group 2	Wedge Failure
6	15>JD> 25	Group 2 and 3	Wedge Failure
7	15>JD> 25 and 5>JD> 15	Group 4	Planar Failure

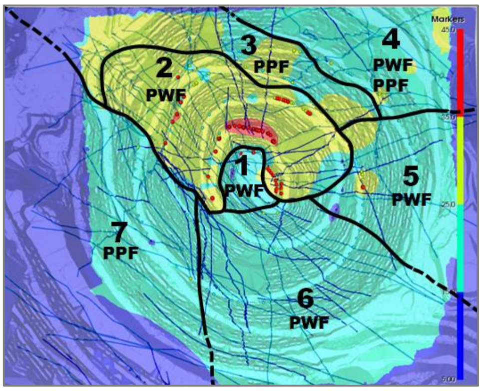

Figure 6. Structural geotechnical domain based on joint density mapping supported by structural model

4. CONCLUSION

Batu Hijau mine is porphyry copper – gold mine with very complex of geological structure. In term of slope stability, the geological structure will play as a major control thus the structural model have to be robust to address and anticipated the pit wall issue. The joint density is one of the physical properties; also it can reflect exposed rock mass quality. Therefore, the joint density mapping can be used to generate the structural geotechnical domain.

This approach for developing structural geotechnical domain is very important and very useful since the process is simple and low cost compared to the benefit gained. However, this joint density information is only based on surficial data from the exposed pit wall. Therefore, additional information is needed to increase the reliability of the model. In this study, the structure model is involved to support and increase the reliability of the structural domain, since the structural domain is developed by surface and sub-surface data. Hence, the structure model will provide additional information related to potential failure type on each domain.

Furthermore, the structural geotechnical domain that generated based on the geological information in the particular joint density can be used as a basic for generating detail of geotechnical domain model for further geotechnical analysis.

The joint density mapping is effective to be performed for generating various geotechnical purposes. However, it should consider to safety standard and requirement, in particular when the mapping is conducted along the active mining and/or high risk area.

5. ACKNOWLEDGEMENT

The authors would like to thanks to Management PT Amman Mineral Nusa Tenggara for allowing and supporting in data collection for completion of this paper. Furthermore, special thanks and grateful to Mr. Hemiel Dayan Lelono for valuable discussion, and Mr. Supardi and Mr. Dedi Maryadi who support and help the author while performing geotechnical mapping to obtain the joint data in the field.

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Paper history:
Received 14 October 2017
Received in revised form 02 January 2018
Accepted 04 January 2018

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چکیده

منطقه تحقیق ناحیه معدن باتو هیجو از معادن جنوب غربی استان تنگارا اندونزی است. منطقه تحقیق بخش عمرانی کنترل شده طبق طرح معماری بخش جنوبی این جزیره است. حضور رژیم معماری فعال که غنی از ذخائر معدنی و ساختار زمین شناسی در این ناحیه است. تمرکز مطالعات بر چگونگی تکامل دامنه زمین شناسی که از اهمیت خاصی در تکامل و طراحی معدن رو باز برخوردار است. این تحقیق نشان داده است که اطلاعات زمین شناسی برای شناسایی دامنه ژئوتکنیکی زمین بسیار مفید می باشد. اطلاعات حاصل از این تحقیق راهنمای مناسبی برای طراحی شیب و پارامترهای موثر معدن روباز است که از ویژگی آن شناسائی خصوصیات ژئوتکنیکی معدن همانند تعیین و بررسی هرگونه خطر و ریسک سقوط و خطا احتمالی ریزش معدن را بررسی نماید.

doi*: 10.5829/ije.2018.31.04a.21*