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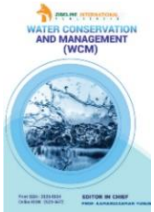

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RESEARCH ARTICLE

IDENTIFICATION OF SECONDARY AQUIFER USING JOINT MODELING AS MINE DEWATERING PRELIMINARY IN LEVEL 7 UNDERGROUND GOLD MINES IN PESISIR SELATAN REGENCY, WEST SUMATRA PROVINCE

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ABSTRACT

Underground gold mining activities are carried out at the research location, Pesisir Selatan Regency, West Sumatra Province. Underground mining method activities will have a higher risk than open mining, so analysis of geological structure, rock mass strength and groundwater conditions is very crucial to maintain mine productivity and safety. During the rainy season at the mine site, runoff water enters the mine through cracks in the walls of the mine hole. Flooding in mine holes is caused by the accumulation of groundwater with large water discharge. Therefore, this research was carried out to determine the direction of the main stress of fractures and will be presented in the form of fracture modeling as an illustration of the distribution of discontinuous planes where groundwater flows from the surface into the mine hole and measurements of the amount of fracture water discharge are carried out to determine the amount of groundwater discharge that enters. into the mine hole through the fracture media. Based on the analysis results, the total water discharge entering the level 7 pit mining area is 0.25 liters/second or the equivalent of 21,600 liters/day. The value of secondary permeability (Ks), which is the ability of rocks to channel water through fractures in rocks, also has quite a large value. The largest secondary permeability value is found in the foot wall fractures with an average permeability value of 25.21 x 10^{-2} m/s, while the average permeability value in hanging wall fractures is 4.21x 10^{-2} m/s . Modeling of fracture conditions shows that rainwater enters the soil and reaches the groundwater zone. Water flowing in the groundwater flow zone flows into cracks in the walls or roof of the tunnel, and produces pools of water at the mining front

KEYWORDS

Underground mine, fractured water discharge, fracture modeling, secondary permeability, secondary aquifer

1. INTRODUCTION

Gold mining activities in Pesisir Selatan Regency, West Sumatra Province use underground mining methods with shrinkage and glory holes, namely where mining is carried out by making levels. In ore mining, rock is crushed by overhand (digging upwards) and allowed to pile up in a stope. Ore mining is carried out horizontally starting from the bottom and heading upwards through a manway. Currently, ore production only takes place in two mine openings, namely the mine holes at Level 6 and Level 7, due to the mine openings at Level 1 to Level 5 have not yet been explored. The ongoing mining is at risk of groundwater infiltration to the mine hole. During the rainy season, runoff water enters the mine site through the gaps between the cracks in the mine hole walls. Discontinuous planes significantly influence the movement of groundwater and play a role in forming groundwater layer systems in the form of fractures, such as joints and fracture zones in rock masses. The fracture zones form complex paths for water to flows (Cook, 2003; Wardani, 2016). At the research location, groundwater can be seen flowing from the gaps between joints. Flooding in mine holes is caused by the accumulation of groundwater with large water discharges. Based on observations made in the mine hole at the research location, Level 7 has the flood which significantly caused problems that will affect productivity and safety. Meanwhile, in Level 6 mine hole, flood is not significant and does not interfere with mining activities which is the reason why the team only focused on Level 7.

Mine water has a significant impact on mine productivity, so various methods are needed to control water flow at the working surface. The large amount of water entering the mining area makes it difficult for workers because this amount of water cannot be removed completely from the mining area. Large amounts of water cover work surfaces and disrupt work activities in mining areas, reducing work time efficiency and resulting in not achieving production targets set by the Company (Wardani, 2016).

Based on the problems that have been explained, the team will mapping the joints and fractures along the walls of Level 7 where the water flows and calculate the secondary permeability value of the fractures, as well as analyze the total amount of water discharge from the fractures. The results of fracture mapping aim to determine the main stress direction of the fracture and will be presented in the form of fracture modeling as an illustration of the distribution of discontinuous planes where groundwater flows from the surface into the mine hole and measurements of the amount of fracture water discharge are carried out to determine the amount of groundwater discharge that enters the mine hole through fractures.

2. MATERIAL AND METHODS

2.1 Research Location

This research was conducted in Pesisir Selatan Regency, West Sumatra Province, Indonesia. Mining Business Permit Area (WIUP) of research location is covering an area of 195 Ha. Underground mining method is

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applied on this gold mining. Primary gold deposits mine requires mining methods by making underground tunnels, according to the mineralogical characteristics, ore geochemistry, vein patterns and alteration of hydrothermal deposits at the mine site.

The stratigraphic conditions of the research area consists of volcanic rock with sedimentary rock insertion. Volcanic rocks are composed of lava, breccia, crystalline tuff, ignimbrite and intermediate tuff, most of which are andesite-dacite. The intermediate tuff consists of fragments of andesite igneous rock, sandy clay, chert, calcite, quartz and feldspar. Crystal tuff contains a lot of feldspar and quartz crystals, the basic mass of which is glass which turns into sericite and clay minerals (Rizky, 2008). Based on the regional structure of Sumatra Island, fault structures and folding structures (anticlinorium) in a general direction northwest-southeast are the structures that developed in West Sumatra Province (Nazaruddin, 1986). The research area is in the Sunda-Banda arc, a magmatic zone of the Sumatran tectonic system. This zone is located in a lowland and undulating area with Pre-mesozoic metamorphic bedrock, Mesozoic metamorphic bedrock, Mesozoic to Cenozoic breccia and Tertiary-Quaternary volcanic bedrock (Hamilton, 1979).

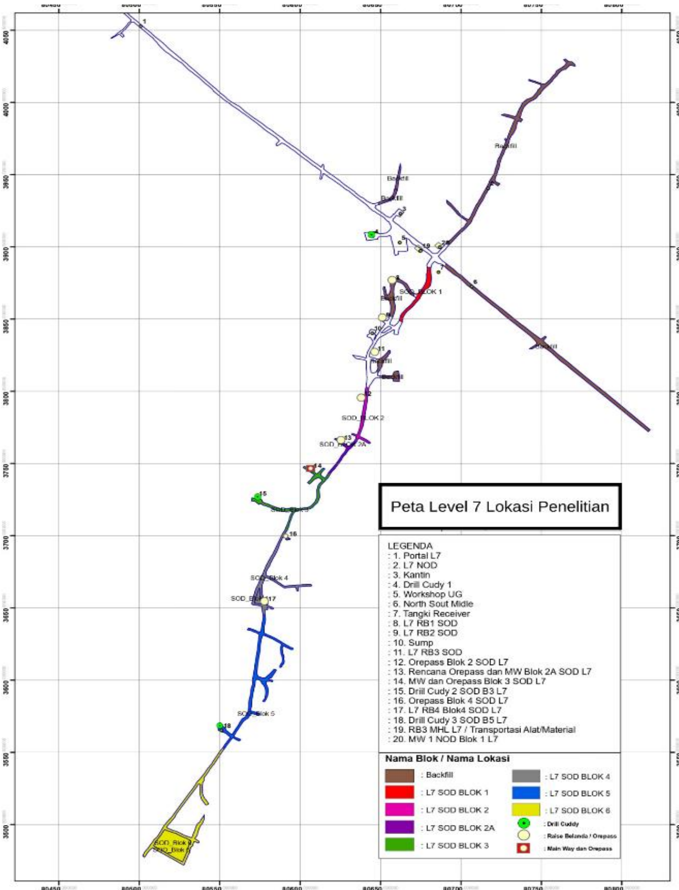


Figure 1: Research Location Mining Hole Layout

2.2 Geological Structure in Hydrogeology

The main direction flow in fractures is along the fracture surface, fault zone and discontinuity zone. Groundwater flow in fractures is influenced by several factors such as pressure, temperature, hardness, geometry, and others. The shape and size of cracks in rock can indicate the presence of fractures. Cracks in rocks can function as channels for water flow. If the rock has primary permeability, then the presence of fractures in the rock can increase the permeability value (Freeze and Cherry, 1979). Therefore, the presence of cracks in soil or rock can cause secondary permeability. Secondary permeability is the ability of rock or soil to drain water formed from fractures (Prastistho et al, 2018). Flow analysis in fractured rocks can be carried out well with a discontinuous approach which is based on the flow hydraulics of each fracture (Freeze and Cherry, 1979). The secondary permeability value can be calculated using the equation (1):

$$\text{Ks} = \frac{\gamma_s (2d)^3}{6.\mu.S} \tag{1}$$

Where: **Ks** is the secondary permeability coefficient of groundwater (meters/second); **γs** is rock specific gravity (kg/m3); **μ** is fluid viscosity (kg/ms); **d** is opening width of the fracture (m); and **s** is the fracture spacing (m).

2.3 Aquifer and Water Fractures Flow

Aquifer refers to a saturated, permeable geological layer that functions to store and transmit water under a normal hydraulic gradient. Hydrodynamically, in nature there are 3 (three) divisions of the aquifer system, namely Confined Aquifer, Unconfined Aquifer, and Leaky Aquifer. Meanwhile, the types of aquifers consist of primary aquifers and secondary aquifers (Fetter, 2001).

Planes of discontinuities in interconnected fractured rock are considered to be the main pathways for fluid flow, with blocks of solid rock considered to be impermeable. Thus, at the scale of the problem in the field, one of two approaches can be followed when dealing with fluid flow in fractured rock, namely continuous and discontinuous (Domenico and Schwartz, 1998). Water infiltration from the earth's surface is usually through the top soil layer, then the water continues to seep into the unsaturated zone (Schwenk, 1965). Two main factors influence the ability of underground water to persist or remain trapped, namely topography and geological structure. The similarity of climatic and geological conditions in the region ensures a similar underground water system. This condition affects the physical and chemical properties and quality of groundwater (Wijaya, 2022).

2.4 Mine Drainage System

Mine drainage is an effort implemented in mining to prevent, dry or remove excessive amounts of water from entering the mining area (Syarifuddin et al, 2017). Another function of the mine drainage system is to extend the service life of equipment and maintain safe working conditions for machines used in mining areas (Khusairi, et al, 2018).

2.4.1 Underground Mine Conveying

The presence of water at the research location comes from groundwater or river seepage, water from drilling, water from filling activities and others. In order to prevent water from entering the production area, efforts have been made to design an underground mine drainage system. The main component in the underground mine drainage system is water discharge. By knowing the water discharge, an underground mine drainage system can be implemented (Indrawan, et al, 2014).

2.4.2 Scanline Fracturing Water Discharge

In the underground mine drainage system at the research location, fracture water discharge measurements are carried out manually. Water discharge can be calculated using equation 2 (Chow, 1985).

$$Q = \frac{V}{t} \quad (2)$$

Where : **Q** is Water discharge (m3/minute); **v** is Water volume (m3); **t** is time (seconds).

In measuring the overall fracture water discharge, use a formula that is appropriate to the type of tunnel. For the research location, the type of tunnel used is arches. The dimensions of the Arches tunnel can be expressed by the following equation (Hartman, et al, 1961):

$$A = \left(\frac{1}{8}\right).\pi.l^2 + \left(h - \frac{1}{2}.l\right).l \quad (3)$$

$$K = \left[(l + 2(\mathrm{h}) + \left(\frac{1}{2}\pi.l\right)\right] \quad (4)$$

The overall fracture water discharge can be calculated using the following equation:

$$\text{Q total} = \frac{A\ Tunnel}{A\ Scanline}\ x\ Q\ scanline \quad (5)$$

Where: **Q** is Water discharge (m3/minute); **A** is Cross-sectional area (m2); **K** is Tunnel circumference (m); **h** is Blanket height (m); **l** is Tunnel height.

2.5 Methodology

This research uses a quantitative type of research. Research involves collecting data systematically and objectively through methods such as surveys, experiments, or data analysis in the form of numbers. The main aim of quantitative research methods is to test the hypotheses that have been formulated.

Primary data was obtained directly in the field. The primary data used in this research is discontinuity data, such as fracture distance, fracture continuity (strike and dip), fracture filling material, and fracture shape. And the fracture groundwater discharge data is used to calculate the total groundwater discharge entering the mine hole through the gaps between the fractures. The secondary data used are mine hole layout maps, topographic maps, geological maps, rock lithology, and mine hole dimensions.

Data processing is carried out on primary data and secondary data that have been obtained in the field, then the secondary permeability value is calculated by first carrying out fracture mapping using the Scanline method which is carried out to obtain the characteristics of fractures which are the main direction of groundwater flow. From the fracture mapping data carried out in the field, fracture analysis was carried out using Dips software to see the dominant fracture direction by obtaining a Rossette Diagram. Then measure the fractured groundwater discharge using a container with a certain volume. To calculate how much water flows through one fracture, this is done by letting the container fill completely with water and calculating the time needed to fill the container.

3. Results

3.1 Fracture Direction Distribution Map

The strike of fracture stress on the mine hole wall is towards East – West and Southwest – Northeast. The presence of geological structures in the form of joints or fractures at this research location indicates the existence of scattered weak zones. The dominant direction of the fracture distribution data shows the East - West direction, which is also the dominant direction of surface water flow which is infiltrated into ground water and stored in rock which flows water through fracture gaps as secondary permeability. The fracture pattern in the research area is a zone with a high level of permeability which allows surface water to flow into subsurface flows. Fracture patterns are also the main factor that influences the existence of subsurface flow (Taslim, 2014). This proves that the groundwater potential in the research location area is controlled by the fracture.

3.2 Fracture Characteristic

The average fracture spacing at the research location is 112 cm on the foot wall and 125 cm on the hanging wall. The description of discontinuous spacing according to the *ISRM Suggested Method*, (1978), fracture spacing at the research location is included in the wide group. The fracture spacing results can be seen in the following table (1).

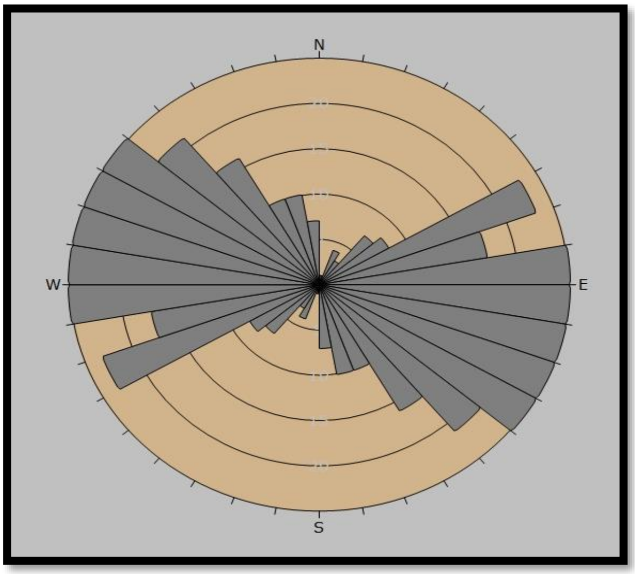


Figure 2: Distribution of fracture Stress Direction measured in Level 7

Table 1: Description of Discontinuous Spacing

Spacing (cm)	Description
< 2	Extremely closed
2 – 6	Very closed
6 – 20	Closed
20 – 60	Moderate
60 – 200	Wide
200 – 600	Very Wide
< 600	Extremely Wide

The average fracture spacing measured is between 1.7 – 2.9 mm, which according to the fracture separation table is included in the Open to Very Open (Gapped) classification group (ISRM Suggested Method, 1978). Meanwhile, according to the condition of the fracture openings at the research location is included in the Open to Open Widely (Gap Fracture) category (Barton And Choubey, 1977). The results of fracture openings can be seen in table 2.

The average value of the fracture length measured was 1.4 meters. Classification and persistence weighting values shows that the average fracture length at the research location has a low persistence level. The results of the fracture length can be seen in table 3 (Bieniawski, 1989).

Table 2: Fracture Spacing Classification

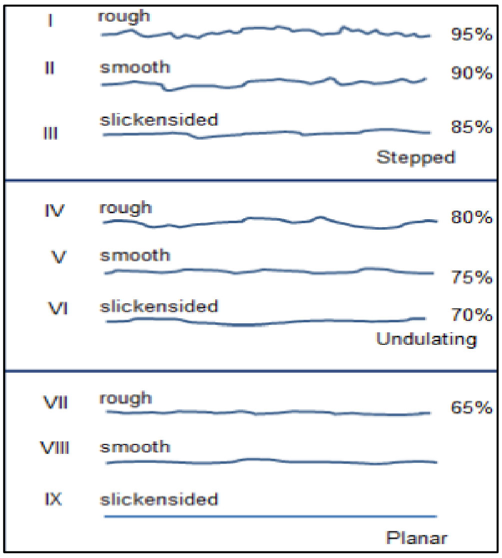
Description of Fracture Spacing (ISRM Sugested Method, 1978)			Description of Fracture Spacing (Barton And Choubey, 1977)		
Spacing	**Description**	**Classification**	**Spacing**	**Description**	**Classification**
< 0,1 mm	Very Closed	Closed	< 0,1	Locked very tightly	Closed Fracture
0,1 – 0,25 mm	Closed		0,1 – 0,25	Locked tightly	
0,25 – 0,5 mm	Partly Closed		0,25 – 0,50	Partly Open	
0,5 – 2,5 mm	**Open**	Gapped	**0,50 – 2,50**	**Open**	Gap Fracture
2,5 – 10 mm	**Very Open**		**2,50 – 10**	**Open Widely**	
> 10 mm	Wide		10 – 100	Open Very Widely	Open Fracture
1,0 – 10 cm	Very Wide	Open	100 – 1000	Extremely Wide	
10,0 – 100 cm	Extremely Wide		>1000	Big Gap	
> 100 cm	Open				

Table 3: Classification and Persistence Weighting Values (Bieniawski, 1989)

Persistence Level	Joint Length (m)	Weighting Value
Very Low	< 1	6
Low	1 – 3	**4**
Intermediate	3 – 10	2
High	10 – 20	1
Very High	> 20	0

On the mine hole walls, the fracture surface texture is classified as a rough texture. According to the roughness profile of fracture surface and roughness classification it classified as fracture with a rough wavy surface, and Undulating sturdiness (ISRM, 1981; Bieniawski, 1976). The fracture roughness results can be seen in the following figure and table.

The condition of groundwater in fractures affects the results of measuring groundwater flow discharge. If the groundwater in the fracture moves at high speed, then the measured groundwater flow discharge will also be large. The condition of groundwater at the research location is analyzed by visual observation of the tunnel walls and can then be expressed in general conditions such as flowing water, dripping, damp and dry. The results of the fracture conditions can be seen in Figure 4.



(a)

Surface Roughness	Description
Very rough	very uneven, forming a ridge at an angle to the flat surface that is close to vertical
Rough	**Wavy, uneven surface, solid surface feels rough.**
Slightly rough	Surface grains are clearly visible, distinguishable and can be felt when touched.
Smooth	The surface is flat and feels smooth when touched.
Slikensided	The surface looks shiny

(b)

Figure 3: (a) Profile of Fracture Surface Roughness; (b) Roughness Classification (Bieniawski, 1976)

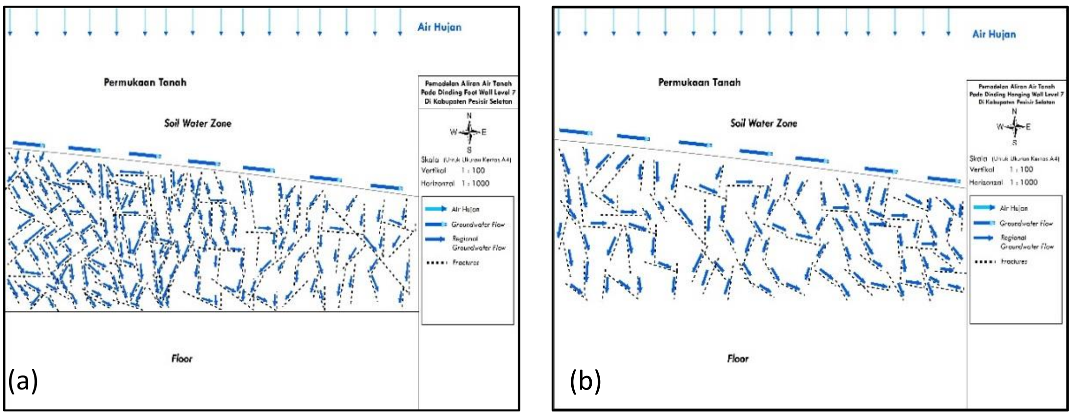


Figure 4: (a) Fracture in Footwall; (b) Fracture in Hangingwall

3.3 Secondary Permeability Values

The foot wall and hanging wall are the walls on the right and left wall of the Level 7. The results of secondary permeability values for fractures in the foot wall according to Snow, 1968 and Cook, 2003 can be seen in table below (Table 4).

Table 4: Secondary Permeability Values (Ks)		
Scanline	**Ks (m/s)**	
	Snow (1968)	**Cook (2003)**
Footwall	4,21 x 10^{-2}	10^{-4}
Hanging Wall	25,21 x 10^{-2}	10^{-4}

The secondary permeability value (Ks) can be the basis for classifying groundwater flow potential. The potential for groundwater flow is based on the greatest permeability value. Groundwater flow potential is divided into high, moderately high, medium and low groundwater flow potential (Singh, 2010).

The calculation results of the secondary permeability (Ks) value at the research location according to is 10-4 m/s, which if adjusted to the groundwater flow potential classification table according to is included in the classification of High Discharge in *slightly-open fract rock* (Cook, 2003; Singh, 2010). The results of the analysis can be seen in Table 5.

Table 5: Classification of Groundwater Flow Potential Based on Secondary Permeability Values (Singh, 2010)			
Class	**Ks (m/s)**	**Lithology**	**Jointed Rocks**
Impermeable	10^{-12}	Slate	
	10^{-11}	Dolomite	
	10^{-10}	Granite	
	10^{-9}	Limestone Sandstone	
	10^{-8}	Limestone Sandstone	Filled with clay
Low Discharge	10^{-7}		fract
Poor	10^{-6}		
Drainage	10^{-5}		
High Discharge	$\mathbf{10^{-4}}$		**Slightly-open fract**
Free Discharge	10^{-3}		
	10^{-2}		open fract
	10^{-1}		Widely-open fract

3.4 Scanline Data

From the scanline data measurement results, a comparison of data processing results can be analyzed regarding fracture characteristics, permeability values, groundwater flow potential, and the amount of water discharge on the foot walls and hanging walls at the research location. The processing results can be seen in Table 11 below. The most groundwater flow through fractures comes from the foot wall with a water discharge of 0.0408 liters/second and a secondary permeability value of 25.21 x 10^{-2} m/s, while in the hanging wall, the groundwater discharge through fractures is 0.0108 liter/second and a secondary permeability value of 4.21 x 10^{-2} m/s.

Table 6: Scanline Data		
Parameters	**Footwall**	**Hanging Wall**
Average Discontinuous Spacing	112 cm	125 cm
Fracture Aperture	2,9 mm	1,7 mm
Filling Material	Quartz dominant, partially absent	Quartz Dominant, partially absent
Secondary Permeability (Ks) based on Snow (1968)	25,21 x 10^{-2} m/s	4,21 x 10^{-2} m/s
Secondary Permeability (Ks) based on Cook (2003)	10^{-4}	10^{-4}
Water discharge	0,0408 lt/s	0,0108 lt/s

The tunnel area at the research location is 1401.6 m2. The total fracture water discharge as a whole is obtained from the comparison of the tunnel wall area with the scanline wall area to the scanline fracture water discharge.

4. Discussion

In the surface area of the research location, there is a large river flow which is also one of the sources of water entering the mine hole. In the relationship between geological structure and hydrogeology, infiltrated surface water will become ground water and be stored in rock media and flow through fractures as a secondary permeability medium. To obtain information regarding the distribution of fracture intensity, accurate data was collected using the scanline method. This method is carried out by drawing straight lines on joint planes and recording the characteristics of the joints cut by these lines, including the direction of fracture orientation, aperture, length, fracture content, and distance between fractures.

Fracture spacing is defined as the distance between two fracture edges that are opposite each other. In a hydrogeological context, fracture spacing can influence secondary permeability and water flow within the fracture system. The larger the fracture spacing, the easier it is for water to flow through the fracture gap, so that the secondary permeability value will also increase and vice versa.

The results of the classification of fracture opening values are closely related to the secondary permeability values, because the size of the fracture opening value will affect the ability of the fracture to drain water. According to the fracture opening value is directly proportional to the secondary permeability value (Snow, 1968). With the results of the analysis that has been carried out, the fracture opening value at the research location is quite large, so it is possible that the fracture's ability to drain water will also be large.

The length of the discontinuity can affect the potential for water flow through the fracture. The longer the discontinuity area, the more surface available for water to flow, so the potential for water flow through the fracture will be greater. However, apart from the length of the fracture, other factors such as roughness and the opening of the discontinuity plane also influence the potential for fracture water flow (Fetter, 2001).

There is a complex relationship between the width of the fracture opening, the distance between the fractures, and the permeability of the rock. In general, the wider the fracture opening, the higher the rock permeability value. However, when the distance between fractures also increases, the rock permeability value can decrease even though the width of the fracture opening remains the same. Therefore, even though the width of the fracture opening is large, if the distance between the fractures is also large, the rock permeability value can decrease.

Most of the groundwater flow through fractures comes from the foot wall, this is because the space between the fractures in the foot wall is smaller than the space in the hanging wall, and the width of the openings in the foot wall is greater than the width of the openings in the hanging wall. However, according to the classification of groundwater flow potential cracks in the foot wall and hanging wall are both included in the potential for quite large water flow (Singhal, 2010).

From the fracture condition model, it shows that rainwater that falls to the ground surface will seep into the ground and reach the groundwater zone. The water that flows in the groundwater flow zone flows into the cracks in the walls or roof of the tunnel, and results in puddles of water at the mining front.

The many fractures in the mine hole at the research location are a type of secondary aquifer and act as a source of groundwater that flows to the mining front. To determine the amount of water entering through the fractures, direct measurements were carried out in the field on the foot wall and hanging wall of the Level 7 mine hole. The calculated results of the flow of water flowing and dripping in the fracture walls of the foot wall and hanging wall of the mine hole were 0.05155 liters/ second. And the total water discharge from fractures in the mine hole is 0.25 liters/second.

5. Conclusion

The direction of stress from fracture mapping is east – west and southwest – northeast. The dominant direction of the fracture distribution data shows east – west which is also the dominant direction of surface water flow that is infiltrated into ground water.

The secondary permeability (Ks) value at the research location is quite large, and the potential for groundwater drainage will also be large. The largest secondary permeability value is found in the fractures in the foot wall, namely with an average Ks value of 25.21 x 10^{-2} m/s, while the average Ks value in the fractures in the hanging wall is 4.21 x 10^{-2} m/s.

The results of calculating the water discharge in the fracture using a scanline on the foot wall and hanging wall of the mine hole were 0.05155 liters/second. The overall fracture water discharge measurement in the mine hole was 0.25 liters/second.

Author Contributions

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