PROCEEDINGS OF

ARMS 9
Bali 2016

9th ASIAN ROCK MECHANICS SYMPOSIUM

"Harmonizing Rock Mechanics with Sustainable Economic Development"

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Telp. 022 - 2504257. Fax. 022 - 2534155
e-mail : itbpress@penerbit.itb.ac.id
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LEGEND		
EN	:	ENERGY
IN	:	INFRASTRUCTURE
RMC	:	ROCKMASS CHARACTERIZATION
CMNM	:	CONSTITUTIVE MODELS & NUMERICAL MODELLING
RE	:	ROCK EXCAVATION
UMOS	:	UNDERGROUND MINE OPENING STABILITY
OPSS	:	OPENPIT SLOPE STABILITY

Evaluation of Ground Support by Rock Mass Index and Finite Element Method Numerical Modelling PT Cibaliung Sumberdaya Banten

A. Adhareza[a*], S. Saptono [a] and B. D. Nagara[a]
[a] *Mining Engineering, UPN "Veteran" Yogyakarta*
*adhareza.adriel@gmail.com (*corresponding author's E-mail)*

Abstract

PT Cibaliung Sumberdaya is one of gold mining company which using cut and fill method for the underground mining system. In underground mining system, all activity doing in ground from surface. The common problem in underground mining activity is the instability of tunnel. Thus, the corrective action needed is evaluate the ground support system itself.

System of ground support certainly requires an analysis from a safety and economic part. Ground support system should be revised refer to mining progress or based on emerging technology in mining area. The evaluation aims to update the primary ground support system in mining which applied by recommendation of Geotechnical Unit, Dept. Quality Control, PT Cibaliung Sumberdaya classified by Rock Mass Rating (RMR) with the new ground support system classified by Rock Mass index (RMi) ones. The meaning of evaluation is to evaluate from a ground support quantity aspect (total split set requirement and thickness of shotcrete) and ground support effective aspect to gain a high safety value. Manual calculation about safety factor (FK) value, plastic zone, stress distribution surrounding the tunnel also available with added a total displacement and strength factor (SF) value from analysis of numerical calculation finite element method with Phase2 v.07 to ensure the empiric method. Result of research in 3 locations e.g Cikoneng Decline, Cikoneng Xcut 2B level 1125 North, Cikoneng Xcut 4 level 1065 Ore Drive 1 South, evaluation of ground support system by Rock Mass index (RMi) more efficient from support quantity and effective from support utility, also give a high value of safety factor for a tunnel.

Keywords: Underground Mine, Ground Support, Rock Mass Classification, Finite Element

1. Introduction

In geographic, PT Cibaliung Sumberdaya located in end South West of Java and in administrative located in Province of Banten. In astronomic, the location of PT Cibaliung Sumberdaya occur at 6˚ 30′ - 6˚ 52′ S and 102˚ 02′ - 105˚ 37′ E. To go to this location from Jakarta could be reached by car transportation via Jakarta – Serang – Pandeglang – Labuan - Cibaliung route in 6 (six) hour.

The purpose of this research is to evaluate the ground support by RMi with the ground support which applied in PT Cibaliung Sumberdaya and compare with numerical modelling (finite element method) to reach an effective and efficient ground support for the tunnel instability potential in underground mining. The limitation of this research is do in Cikoneng area only and the critical condition of stability (safety factor) calculated by Mohr-Coulomb failure criterion. The rock mass classified with Rock Mass index (RMi) by Arild Palmström (2000) and the numerical modelling was calculated and presented with software Phase2 v.07.

2. Theories (or Experiments)

2.1 Theories

Rock Mass index (RMi) is a classification system based on inherent of the rock mass. Basically, this system combine the compressive strength from the intact rock and the parameter of joint condition.

There are 5 (five) input parameters to classify the rock mass by RMi system: Uniaxial of compressive strength (c), Volume block (Vb), Joint roughness factor (jR), Joint alteration factor (jA), and Joint continuity factor (jL). The value of Rock Mass index (RMi) parameters could be shown in Table 1.

Table 1 Value of rock mass index (RMi) input parameters

Uniaxial compressive strength of intact rock (σ_c)	**value** in MPa (from lab. tests or assumed from handbook tables)
Block volume (Vb)	**value** in m³ (from observations at site or on drill cores, etc.)
Joint condition factor (jC)	**jC = jR x jL / jA** (ratings of jR, jA and jL from the tables below)

jR (joint roughness factor, which is composed of large scale and small scale undulations, similar to Jr in the Q-system)

(The ratings in ***bold italic*** are similar to Jr)	Large scale waviness of joint plane: Planar	Slightly undulating	Undulating	Strongly undulating	Stepped or interlocking
Small scale smoothness of joint surface: Very rough	2	3	4	6	6
Rough	***1.5***	2	***3***	4.5	6
Smooth	***1***	1.5	***2***	3	4
Polished or slickensided *)	***0.5***	1	***1.5***	2	3
For filled joints jR = 1 For irregular joints a rating of jR = 6 is suggested					

**) For slickensided surfaces the ratings apply to possible movement along the lineations*

jA (joint alteration factor, which ratings are based on Ja in the Q-system)

Contact between joint walls	CLEAN JOINTS:	Healed or welded joints	filling of quartz, epidote, etc.		jA = 0.75
		Fresh joint walls	no coating or filling, except from staining (rust)		1
		Altered joint walls	- one grade higher alteration than the rock		2
			- two grades higher alteration than the rock		4
	COATING or THIN FILLING OF:	Frictional materials	sand, silt calcite, etc. without content of clay		3
		Cohesive materials	clay, chlorite, talc, etc.		4
Partly or no wall contact	THICK FILLING OF:	Frictional materials	sand, silt calcite, etc. (non-softening	jA = 4	8
		Hard, cohesive materials	clay, chlorite, talc, etc.	6	5 - 10
		Soft, cohesive materials	clay, chlorite, talc, etc.	8	12
		Swelling clay materials	material exhibits swelling properties	8 - 12	13 - 20
				Thin filling (< 5 mm)	Thick filling

jL (joint size factor, which is composed of the length and continuity of the joint)		***Continuous joints***	***Discont. joints****
Bedding or foliation partings	length < 0.5 m	jL = 3	jL = 6
Joints	with length 0.1 - 1 m	2	4
	with length 1 - 10 m	1	2
	with length 10 - 30 m	0.75	1.5
(Filled) joint, seam or shear **)	length > 30 m	0.5	1

*) Discontinuous joints end in massive rock **) Often a singularity and should in these cases be treated separately

There is a formula to define the value of RMi based on the jointed rock, as shown in Eq.1

$$RMi = \sigma_c \cdot JP \quad (1)$$

where σ_c = uniaxial compressive strength based on the UCS/PLi test
JP = joint parameter value

To define the value of joint parameter (JP) can be found

$$JP = \sigma_c \cdot 0.2\sqrt{jC} \cdot Vb^{D} \quad (2)$$

where jC = joint condition factor
Vb = block of rock volumes (m^3)
Db = diameter of rock block (m^3)

$$Db = \sqrt[3]{Vb} \quad (3)$$

$$D = 0.37 \cdot jC^{-0.2}$$

RMI is obtained a value of RMi on tunnel or hole openings are examined. There are 6 (six) class on the value of the RMI. For more details can be seen in the following table

Table 2 Rock mass index (RMi) classification

RMi =	100	-	40	Very high
RMi =	40	-	10	High
RMi =	10	-	1	Moderate
RMi =	1	-	0.4	Low
RMi =	0.4	-	0.1	Very low
RMi =	0.1	-	0.01	Extremely low

Values of the RMi obtained must be calculated again based on continuity of rock mass factor (CF). Continuity of rock mass factor is a factor of joint continuity. If joint that does not intersect with another joint then it can be said to be of continuity of ground type is massive or highly jointed or particulated (CF < 5 or > 100). If the joint intersect with other joint, then it can be said the continuity of ground type is jointed (CF 5 to 100). The value of the CF was obtained from the following formula

$$CF = Dt\ (span) / Db \tag{4}$$

where Dt = tunnel diameter
Db = the diameter of rock blocks

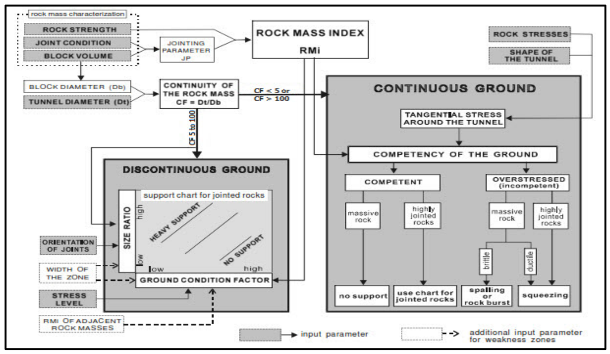

Fig.1 . Rock mass index (RMi) flowchart

The value of the CF can be grouped into 2 (two) type continuity of the ground. For a continuous ground, the value of the RMi will be calculated to get the value of the competency of the ground (Cg) based on the value of tangential pressure (σθ). And, the value of tangential pressure (σθ) around the hole openings of the pressure of rocks either vertically (ρv) and horizontal (ρh), influence of ground water (ground water), shape, span (Wt), and the diameter of the hole openings (D). For discontinuous ground, the value of the RMi will be calculated to get the value of the ground condition factor (Gc) based on the stress factor level (SL) and the size ratio (Sr) based on the orientation of the joint. For more details and calculations in determining any needs of the RMi obtained, it as shown in Figure.1 .

2.2 Experiments

1. Rock Mass Condition and Properties

Mechanical and physical properties of rock mass can be seen in Table 3 as follows:

Table 3 Mechanical & physical properties of rock mass

No	Location	Rock Mass	σc (MPa)	GSI	Cohesion (c)	Angle of Friction (˚/deg)	Young Modulus (MPa)	Tensile Strength (MPa)
1	Cikoneng Decline	Porphiry Andesite	36.3	34	0.42	40.19	978.61	0.01
2	Cikoneng Xcut 2B level 1125 North	Quartz Vein Breccia – Clay Matrix Breccia – Porphiry Andesite	64.5	36	0.25	46.76	1561.60	0.01
3	Cikoneng Xcut 4 level 1065 Ore Drive 1 South	Stockwork – Clay Matrix Breccia – Quartz Vein	53.7	33	0.35	37.91	1197.46	0.01

2. Joint Condition (jC)

Joint Condition (jC) obtained from the calculation of the 3 parameters i.e. joint roughness (JR), joint alteration (jA), and the joint length (jL). For more details can be seen in Table 4 below.

Table 4 Joint condition (jC)

No	Location	Joint Roughness (jR)	Joint Alteration (jA)	Joint Continuity (jL)	Joint Condition (jC)
1	Cikoneng Decline	2 (slightly undulating – rough)	4 (thin filling – clay)	1.5 (10 – 30 m)	0.75
2	Cikoneng Xcut 2B level 1125 North	3 (undulating – rough)	4 (thin filling – clay)	2 (1 – 10 m)	1.5
3	Cikoneng Xcut 4 level 1065 Ore Drive 1 South	3 (undulating – rough)	3 (thin filling – silica)	2 (1 – 10 m)	2

3. Joint Parameters (JP) and the value of the Rock Mass index (RMi)

Joint Parameter is the parameter values obtained from joint based on the calculation of the value of the volume of blocks rocks (Vb), contants D, and joint condition (jC). Based on the value of this JP can be calculated the value of Rock Mass index (RMi) at each location. For more details can be seen in Table 5 as follows.

Table 5 Joint parameter (JP)

No	Location	Joint Condition (jC)	Volume of Block Rocks (Vb)	Konstanta D	*Joint Parameter* (JP)	RMi Value
1	Cikoneng Decline	0.75	0.200 m^3	0.39	0.090	3.27 (III – moderate)
2	Cikoneng Xcut 2B level 1125 North	1.5	0.070 m^3	0.34	0.099	6.39 (III – moderate)
3	Cikoneng Xcut 4 level 1065 Ore Drive 1 South	2	0.004 m^3	0.3	0.043	2.31 (III – moderate)

4. Continuity Factor (CF)

Cikoneng Decline tunnel diameter i.e. 4.78 m and the value of the Db that is 0.62 m so that the value of the CF gained i.e 8 with the category of discontinuous ground. As for the location of Cikoneng Xcut 2B level 1125 North tunnel diameter i.e. 5.11 m and the value of the Db that is 0.41 m so that the value of CF obtained i.e. 12 with the discontinuous category. Then, for the location of the 1065 level 4 Xcut Cikoneng Ore Drive 1 South has a diameter tunnel i.e 4.32 m and the value of the Db that is 0.16 m so that the value of CF obtained i.e. 27 with the discontinuous category of ground.

5. The Influence Surrounding the Tunnel

Based on the results of the calculations are then obtained the influence of stress level (SL), groundwater (GW), factor of joint set adjustment (Nj), the inclination and orientation on the roof and the wall as follows. (see Table 6).

Table 6 Influence of stress level, groundwater, the inclination and orientation

No	Location	Stress Level (SL)	Ground -water (GW)	Roof Inclination (C_{roof})	Wall Inclination (C_{wall})	Roof Orientation (Co_{roof})	Wall Orientation (Co_{wall})	Factor of Joint Set Adjustment (Nj)
1	Cikoneng Decline	1.50	1	2.80	2.30	1	2	0,50 (6 joint sets)
2	Cikoneng Xcut 2B level 1125 North	1.50	1	2.60	3.30	1	1.50	0,75 (4 joint sets)
3	Cikoneng Xcut 4 level 1065 Ore Drive 1 South	1.50	1	3.60	1.90	1	1.50	1,50 (2 joint sets)

6. Ground Condition (Gc), Size Ratio (Sr), and the Determination of Bolt Length (Lb)

Here are graphs that contain a combination of support quantity needs from Ground Condition (Gc), Size Ratio (Sr) values and bolt length (Lb). (see Table and Figure below).

Table 7 Ground condition (Gc), size ratio (Sr), and bolt length (Lb)

No	Location	Ground Condition (Gc)		Size Ratio (Sr)		Bolt Length (Lb)	
		Roof	Wall	Roof	Wall	Roof	Wall
1	Cikoneng Decline	14	11	16	26	1.4 m	2.0 m
2	Cikoneng Xcut 2B level 1125 North	25	32	17	25	1.5 m	2.1 m
3	Cikoneng Xcut 4 level 1065 Ore Drive 1 South	12	7	18	27	2.5 m	1.4 m

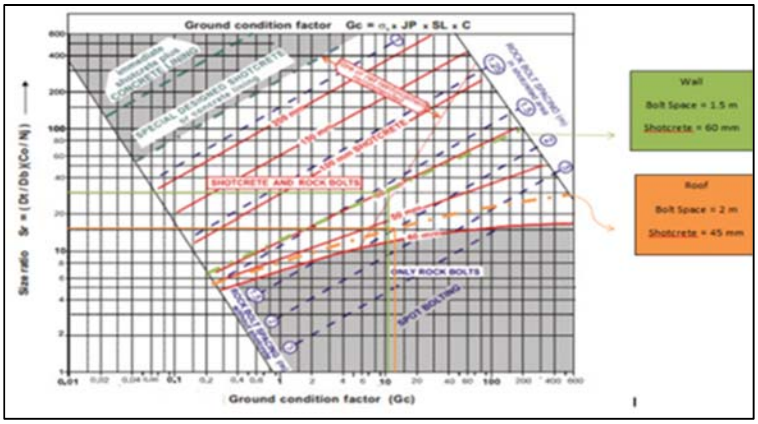

Fig. 2. Cikoneng decline rockbolt and shotcrete support combinations

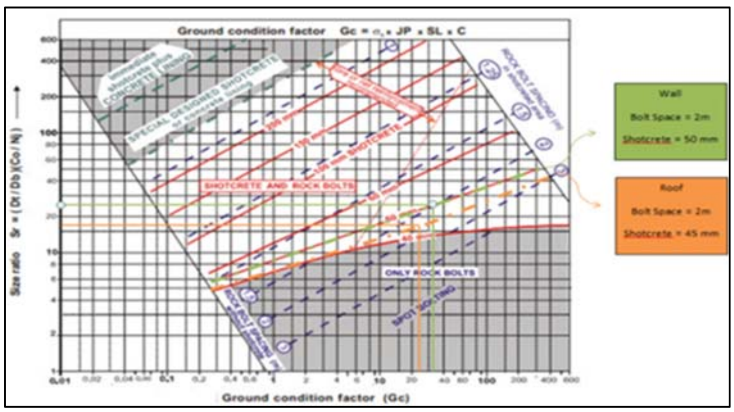

Fig. 3. Cikoneng xcut 2b level 1125 north rockbolt and shotcrete support combinations

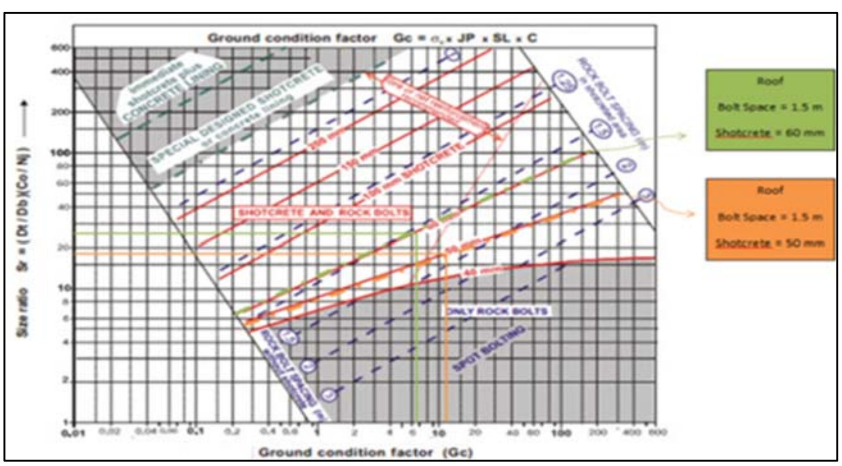

Fig. 4. Cikoneng xcut 4 level 1065 ore drive 1 south rockbolt and shotcrete support combinations

7. Safety Factor, The Rate of Displacement, Distribution of Stress Surrounding the Tunnel, and Plastic Zone

Table 8 Safety factor, the rate of displacement, distribution of stress, and plastic zone

		Cikoneng Decline		Cikoneng Xcut 2B level 1125 North		Cikoneng Xcut 4 level 1065 Ore Drive 1 South	
		Roof	Wall	Roof	Wall	Roof	Wall
Safety Factor		0.97	1.56 – 1.65	0.61	0.72 – 0.74	0.66	1.28 – 1.39
Rate of Critical Displacement (Vr)		51.822×10^{-5} mm/day		37.570×10^{-5} mm/day		49.460×10^{-5} mm/day	
Rate of Maximum Displacement (Vr max)		33.273×10^{-2} mm/day		28×10^{-3} mm/day		61×10^{-3} mm/day	
Distribution of Stress Surrounding the Tunnel (MPa)	Major Stress (σ_1)	3.63	1.00	2.80	1.44	1.75	0.78 – 0.86
	Minor Stress (σ_3)	0.43	0.08 – 0.11	0.34	0.12	0.21	0.14
	Vertical Stress (σ_v)	3.34		1.41		2.98	
	Horizontal Stress (σ_h)	1.04		0.65		0.98	
	Radial Stress (σ_r)	0		0		0	
	Tangential Stress (σ_θ)	7.83	-0.22	3.58	0.54	7.96	-2.02
	Shear Stress ($\sigma_{r\theta}$)	0		0		0	
Plastic Zone (m)		1.74		1.71		1.61	

3. Result and Discussion

1. Support Requirement

Table 9 Support requirement

No	Location	Rock Mass Value	Rockbolt (Splitset)		Shotcrete Thickness	Additional
			Space	Quantity		
1	Cikoneng Decline	RMi = 3.26	1.5 – 2 m	8 pcs	1st layer 45 – 60 mm	
		RMR = 39	1.20 m	11 pcs	1st layer 50 mm, 2nd layer 100mm fibrecrete	Forepolling 2.40 m
2	Cikoneng Xcut 2B level 1125 North	RMi = 6.37	2 m	7 pcs	1st layer 45 -50 mm	
		RMR = 41	1.50 m	9 pcs	1st layer 50 mm	
3	Cikoneng Xcut 4 level 1065 Ore Drive 1 South	RMi = 2.30	1.50 m	8 pcs	1st layer fibrecrete 50 – 60mm	
		RMR = 38	1.10	11 pcs	1st layer 50 mm, 2nd layer 100mm fibrecrete	Forepolling 2.40 m

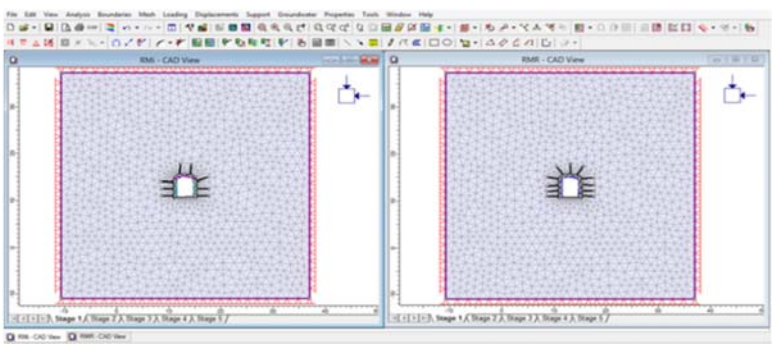

Fig. 5.Cikoneng decline support quantity

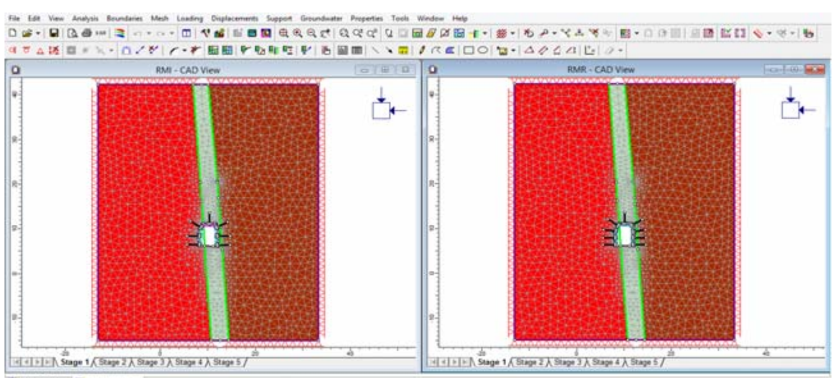

Fig. 6.Cikoneng xcut 2b level 1125 north support quantity

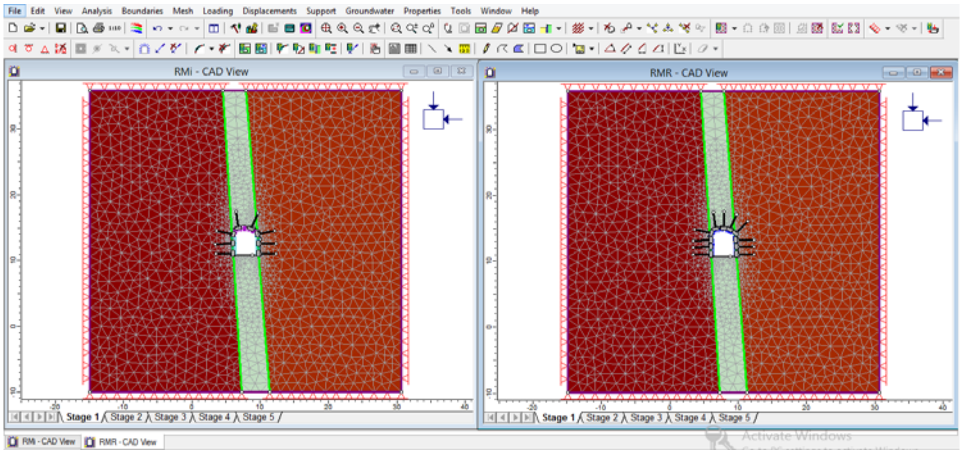

Fig. 7. Cikoneng xcut 4 level 1065 ore drive 1 south support quantity

2. Strength Factor

Table 10 Strength factor value

No	Location	Support Design by Rock Mass Classification	Strength Factor (SF) Value			
			No Support		Supported	
			Roof	Wall	Roof	Wall
1	Cikoneng Decline	RMi	0.95	0.95 – 1.26	1.89	3.16 – 4.11
		RMR			1.89	2.53 – 3.79
2	Cikoneng Xcut 2B level 1125 North	RMi	0.95	0.95	0.95 – 1.58	1.58 – 2.21
		RMR			0.95 – 1.26	1.58 – 2.21
3	Cikoneng Xcut 4 level 1065 Ore Drive 1 South	RMi	0.95	1.26 – 1.89	1.58	3.79 – 4.74
		RMR			1.58	3.47 – 4.79

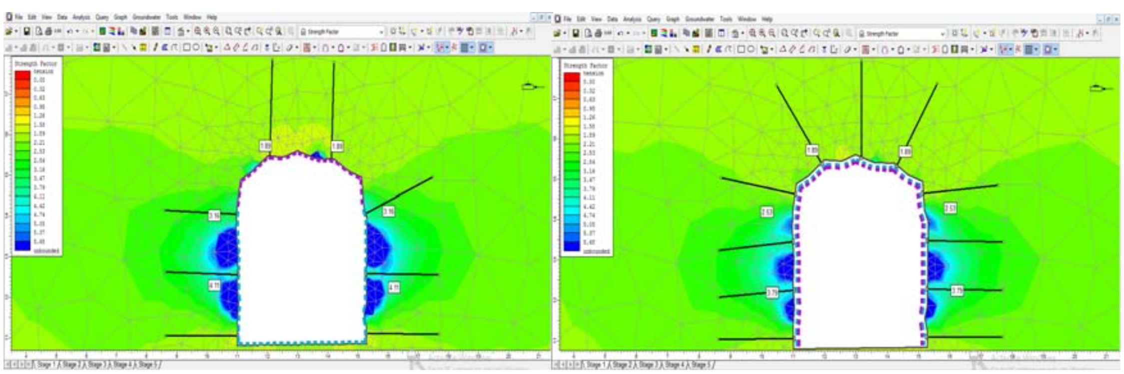

Fig. 8.Cikoneng decline strength factor value

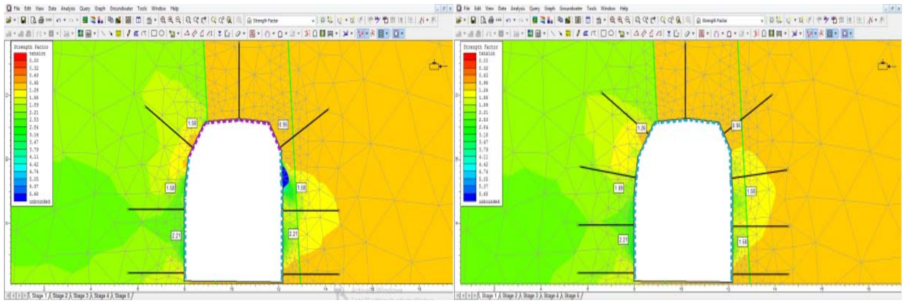

Fig. 9. Cikoneng xcut 2b level 1125 north strength factor value

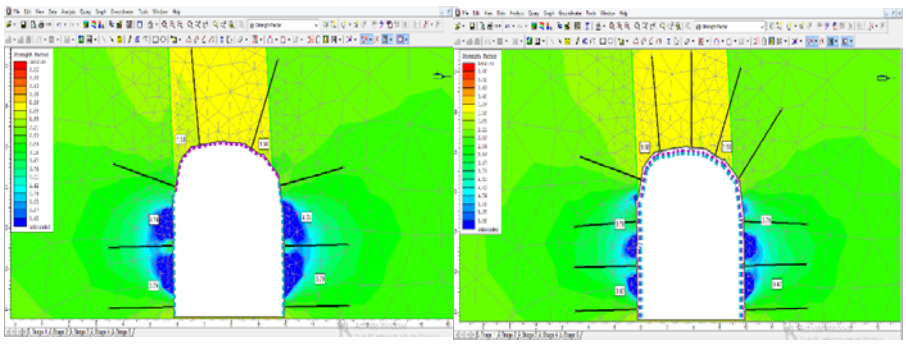

Fig. 10. Cikoneng xcut 4 level 1065 ore drive 1 south strength factor value

4. Conclusions

a. Quantity of rockbolt requirement (splitset) and thickness of shotcrete on the support modelling which classified base on classification of Rock Mass index (RMi) fewer in number of splitset and much thinner in shotcrete also do not require fibrecrete nor forepolling.
b. In general review from support requirements and strength factor value, RMi support design modeling is more effective in support quantity terms as well as efficient in terms of the needs of support.

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