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Rock Mass Classification for Sedimentary Rock Masses in Indonesia Coal Mining Areas

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Abstract. Rock slopes stability is important for personnel and equipment safety in the open-pit mine. Instability and failure of slope occur due to many factors such as unsuited slope geometry, geological discontinuities, weak slope material due to weather influences. External loads such as high rainfall and seismicity could play an essential role in slope failure. Consequently, a precise classification of rock mass is needed for the basis of determining technical policy. Rock slopes in open pit coal mining areas, especially in Indonesia, are characterized by applying various rock mass classification systems, such as Rock Mass Rating (RMR) and Geological Strength Index (GSI), because the study area comprises well-exposed rock formations. In the RMR system, there are five main parameters i.e. Rock Quality Designation (RQD), Uniaxial Compressive Strength (UCS) of rocks, discontinuity spacing, discontinuity and groundwater conditions were considered. Several rock mass classification systems developed for the assessment of rock slope stability were evaluated with the condition of rock slopes in the tropics, especially Indonesian region, particularly in sedimentary rocks in the open pit coal mining area in order to get the corrected GSI equation used to characterize rock slopes based on rock mass structure quantitative analysis and discontinuities surface conditions. This paper provides correlation between the GSI and RMR for sediment rock in coal mines.

INTRODUCTION

One of the easiest ways to changes mine design for efficiency purposes is to minimize the stripping ratio or make the mine slopes both single slopes and overall slopes as high and as straight as possible. This slope conditions will be efficient and effective for mining. However, these dimensional changes could not be immediately realized without knowing the strength of rock mass or stability of mine slope or safety factor. Development of methods for determining slope stability needs to pay attention for a summary of various studies relating to soft rocks, rock mass characterization, the influence of scale, rock strength and rock mass which related to slope stability problems. Research on the strength of soft rocks has been carried out by [[22], [26], [27]]. While in Indonesia [[30], [35], [71], [34], [64]]. The strength characteristics of soft rocks are very susceptible to water content increase, so that rocks will decay and cause a strength decrease from hard to soft rocks [[26], [27]]. This soft rock is often founded in coal mining areas in Indonesia, one of which is the coal mine in Ombilin [[13], [14]]. In addition to increasing the water content, rock strength is also influenced by discontinuities. The effect of discontinuities on rock strength could be determined by laboratory and field testing.

Several methods of estimating rock mass strength have been developed by applying rock mass classification, one of them is Rock Mass Rating (RMR) [[4], [5]]. RMR is the basis for developing more specific rock mass classifications, for example rock mass classification for slope stability analysis. The classification system for slope stability analysis has been developed by several researchers [[60], [61], [41], [52], [65], [51], [11], [46], [19]].

Geological engineering problems that appear during excavation like slope instability, rock mass and groundwater conditions and critical zones as shear zones must to be anticipated. Consequently, the treatments recommended are based on the rock masses classification with measurable parameters. Rock masses behavior is regulated by material

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properties of intact rock and discontinuities. The rock mass strength is given by the shear strength of the discontinuity surface usually depends on several factors such as spacing, orientation, continuity, surface characteristics, separation, thickness and nature of filling material. There are several approaches that classify and characterize rock masses known as geomechanical classifications such as Rock Mass Rating [5] which is based on detailed laboratory and field studies involving data collection on the observation slope. Another approach is the Geological Strength Index (GSI). The GSI value is related to the degree of fracture and conditions of discontiuniuty surface. Hence, the GSI and RMR approache used in this study were focused on the characteristics of sedimentary rock masses in Indonesian coal mines.

LOCATION OF THE STUDY AREA

The location of rock sampling is carried out in several places in lowwall Pit PAMA, SIS, BUMA and RA. Meanwhile, rock mass characterization was carried out in 22 sections consisting of 13 sections in PAMA Pit, 5 sections in the SIS and 4 sections in BUMA Pit and RA. The choice of location for rock sampling and characterization of rock mass is based on the completeness of laboratory and structural data, operational ease and safety. Characterization of rock mass carried out at Tutupan mine, generally on the low wall slope and the measurement locations are marked with Strip (S), Block (B) and RL (Relative Level).

TABLE 1. shows the sampling locations and characterization of rock mass and for the example of large block shear tests are coarse sandstone (BPk), fine sandstone (BPh) and mudstone (BL). The Strip (S) indicates the abscissa from East to West. The higher value of Strip means the location is getting east, and Block (B) expresses the ordinate direction from South to North (**TABLE 1**).

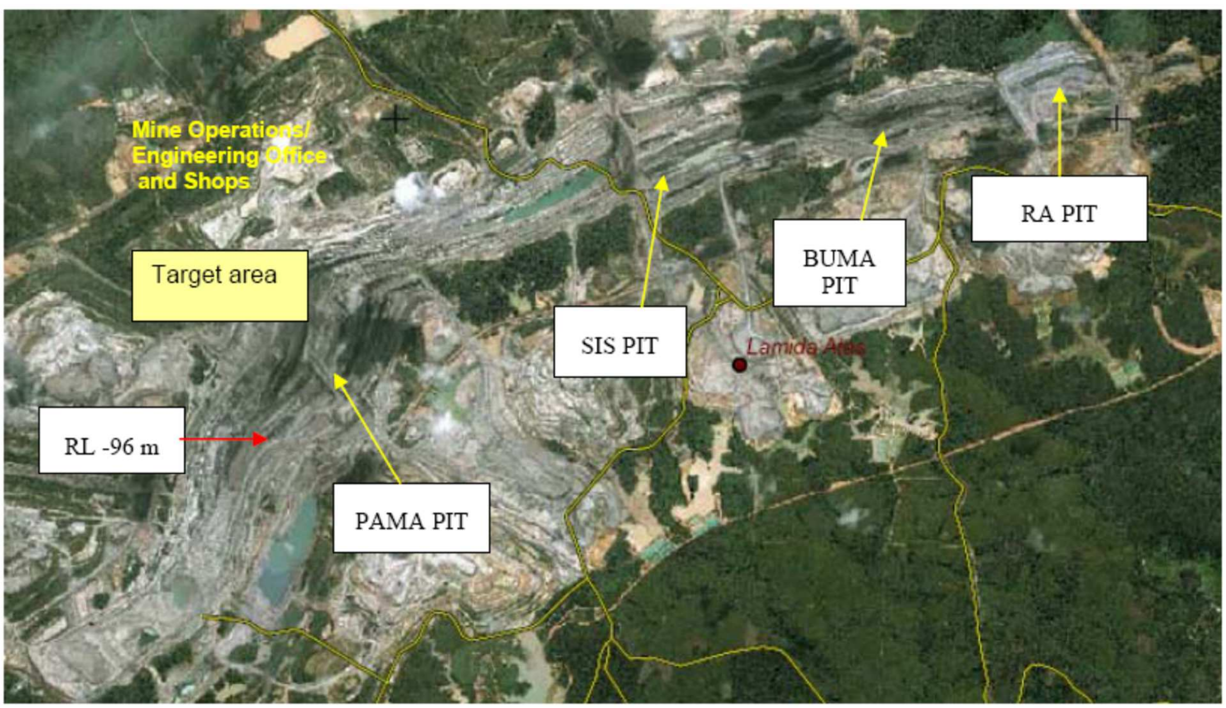


FIGURE 1. Tutupan mine (Saptono & Kramadibrata, 2008 a, b, c)

TABLE 1. Location of rock sampling

Section	Sample code	Location		
		S	B	RL
1	BPk1	40	69	49
2	BPk2	40	64	36
3	BPh1	43	61	-5
4	BPh2	43	61	3
5	BPh3	47	102	80
6	BPh4	44	77	-71
7	BPh5	45	77	-50
8	BPh6	52	103	26
9	BPk3	52	102	26
10	BPk4	52	132	86
11	BPk5	60	144	70
12	BPk6	40	61	64
13	BPk7	40	61	70
14	BPk8	39	67	61
15	BPh7	37	68	70
16	BPh8	46	67	-37
17	BPh9	46	68	-37
18	BPh10	44	96	107
19	BPh11	45	96	108
20	BL1	60	127	108
21	BL2	47	93	88
22	BL3	48	96	102

S = strip, B = block, RL = relative level

ROCK MASS CLASSIFICATION

The rock mass classification used were RMR and GSI classification. The RMR and GSI classification systems can be applied for slope stability analysis, which can determine cohesion and friction angles in rock masses according to rock class as parameters of the Mohr-Coulomb and Hoek & Brown collapse criteria.

Rock Mass Rating (RMR)

The Rock Mass Rating system was invented by Bieniawski to evaluate rock mass quality for underground projects that consists of five basic parameters. The parameters are Uniaxial Compressive Strength of intact rock, RQD, discontinuities spacing, discontinuities condition, and groundwater. Additional parameters were proposed by Bieniawski to explain discontinuity orientation effect on stability conditions. Nevertheless, this parameter wasn't introduced for slopes, but for dam foundations and tunnel. Hence, Bieniawski applies more descriptive details in the fourth parameter of the basic RMR (discontinuity condition). **TABLE 2 and 23**show the RMR classification criteria and their different rock mass classes (Bieniawski, 1989).

TABLE 2. Rock rating system (Bieniawski, 1989)

Parameter		Range of values						
1 Strength of intact rock mineral	Point-load strength index (MPa)	>10	4–10	2–4	1–2	For the low range, uniaxial compression test is preferred		
	UCS (MPa)	>250	100–250	50–100	25–50	5–25	1–5	<1
Rating		15	12	7	4	2	1	0
2 Drill core RQD (%)		90–100	75–90	50–75	25–50	<25		
Rating		20	17	13	8	3		
3 Spacing of discontinuities		>2 m	0.6–2 m	200-600 mm	60-200 mm	<60 mm		
Rating		20	15	10	8	5		
4 Condition of discontinuities (see Table 2)		• Very rough surfaces • Not continuous • No separation • Unweathered wall rock	• Slightly rough surfaces • Separation <1 mm • Slightly weathered walls	• Slightly rough surfaces • Separation <1 mm • Highly weathered walls	• Slickensided surfaces, or • Gouge < 5 mm thick, or • Separation 1–5 mm (Continuous)	• Soft gouge >5 mm thick, or • Separation > 5 mm (Continuous)		
Rating		30	25	20	10	0		
5 Groundwater	Inflow per 10 m tunnel length (L/min)	None	<10	10–25	25–125	>125		
	Ratio of joint water pressure to major principal stress	0	<0.1	0.1–0.2	0.2–0.5	>0.5		
	General condition	Completely dry	Damp	Wet	Dripping	Flowing		
Rating		15	10	7	4	0		

TABLE 3. Guidelines for discontinuity condition classification in RMR.

Discontinuity length (persistence)		Separation (aperture)		Roughness		Infilling (gouge)		Weathering	
Value (m)	Rating	Value (mm)	Rating	Description	Rating	Description	Rating	Description	Rating
<1	6	None	6	Very rough	6	None	6	Unweathered	6
1–3	4	<0.1	5	Rough	5	Hard filling < 5 mm	4	Slightly weathered	5
3–10	2	0.1–1.0	4	Slightly rough	3	Hard filling > 5 mm	2	Moderately weathered	3
10–20	1	1–5	1	Smooth	1	Soft filling < 5 mm	2	Highly weathered	1
>20	0	>5	0	Slickensided	0	Soft filling > 5 mm	0	Decomposed	0

Rating	Class	Description
100–81	I	Very good rock
80–61	II	Good rock
60–41	III	Fair rock
40–21	IV	Poor rock
<20	V	Very poor rock

Geological Strength Index (GSI)

Meanwhile, to determine the rock mass class-based on GSI is divided into two parameters, namely rock mass surface conditions and rock structure. Based on the parameters of the surface conditions of rock masses consisting of very good rocks, good rocks, fair rocks, poor rocks and very poor rocks, while based on rock structure consisting intact rocks, blocky, very blocky, disturbed, disintegrated and laminated (**TABLE 3**).

As input parameters to determine rock mass class of Tutupan area is from the results of the uniaxial compressive strength test, the discontinuities orientation, discontinuities spacing and RQD, the condition of discontinuities and groundwater for each cross-section, and then the results are used as input parameters for classifying the rock mass of each cross-section. The parameters of discontinuities consisting of continuity, spacing, roughness, filling and weathering as well as groundwater condition parameters are rated to obtain the value (**TABLE 4**).

The parameters of uniaxial compressive strength, RQD, and the actual distance of discontinuities are rated to get the value. This is also done on the parameters of discontinuity conditions, groundwater conditions and general orientation of discontinuity conditions for each cross-section (**TABLE 5**). To obtain the value of the RMR for each cross-section by adding up the rate of each parameter. For example, if $\sigma_c = 13.4$ MPa, the value is 2.3, etc.

Based on the sum of the parameters rate show that the highest value of RMR is 71 (cross-section of 5 types of fine sandstone) and the lowest value of RMR is 24 (cross-section of 13 types of coarse sandstone). Based on the (**TABLE 5**) rock mass rating in Tutupan mine could be classified into rock mass class II (good rock) and class IV (poor rock).

TABLE 4. Rock mass classification based on GSI (Hoek & Brown, 2002)

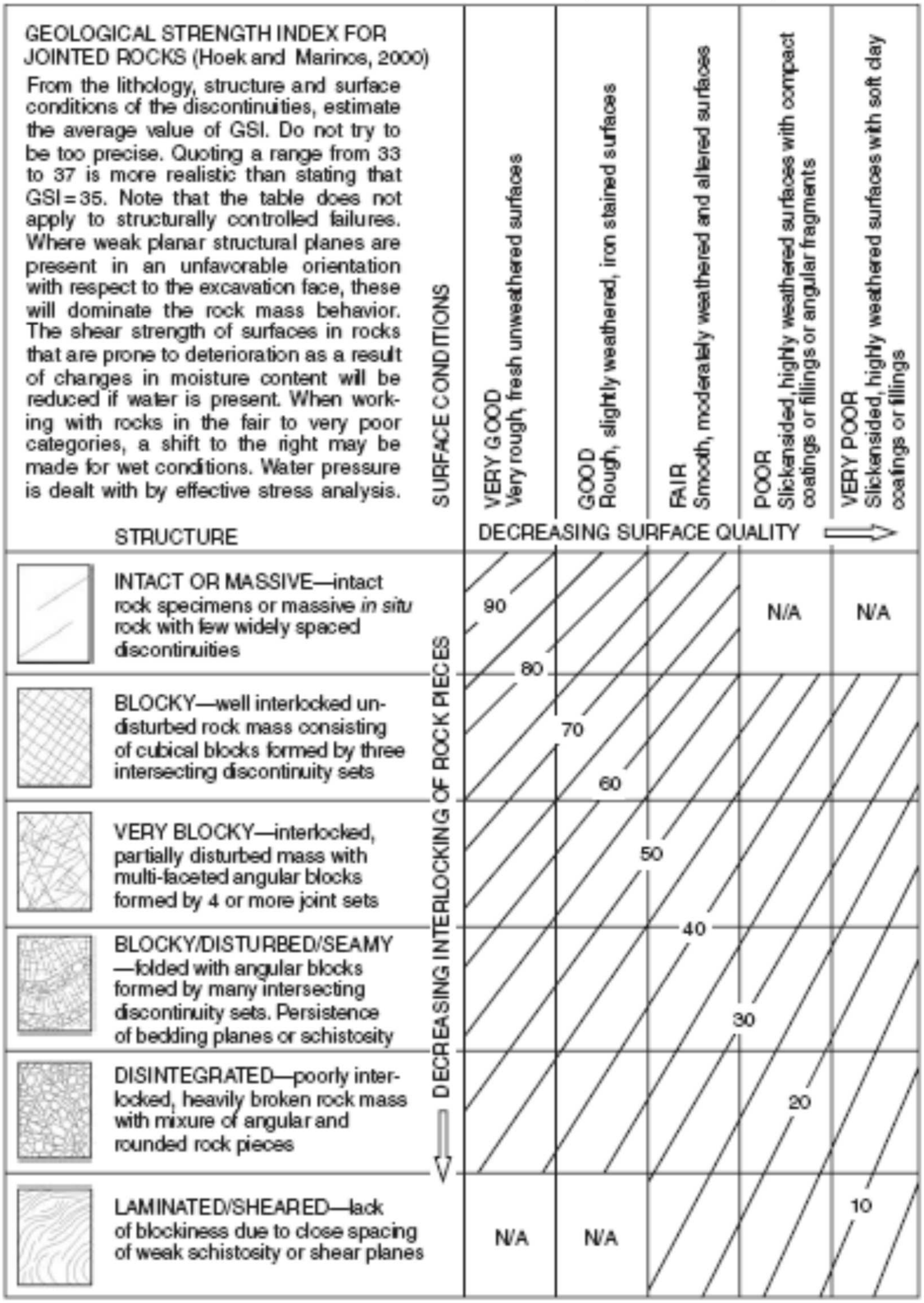


TABLE 5. The characterization results of rock mass discontinuities in Tutupan mine

Cross-section	Rock types	Location			Discontinuities condition						Groundwater condition
		S	B	RL	Continuity		Aperture	Roughness	Filling	Weathering	
					> 0.6 h	< 0.6 h					
1	Coarse sandstone	40	69	49	6%	94%	< 0.1 mm	fine	-	Low rate	dry
2	Coarse sandstone	40	64	36	17%	83%	0.1 - 1.0 mm	fine	Hard filler < 5 mm	Low rate	dry
3	Fine sandstone	43	61	-5	4%	96%	0.1 - 1.0 mm	fine	Hard filler < 5 mm	High rate	moist
4	Fine sandstone	43	61	3	6%	94%	0.1 - 1.0 mm	fine	Hard filler < 5 mm	Low rate	dry
5	Fine sandstone	47	102	80	3%	97%	< 0.1 mm	bit rough	-	Low rate	dry
6	Fine sandstone	44	77	-71	38%	62%	0.1 - 1.0 mm	fine	Hard filler < 5 mm	Low rate	dry
7	Fine sandstone	45	77	-50	35%	65%	0.1 - 1.0 mm	fine	-	Medium rate	dry
8	Fine sandstone	52	103	26	36%	64%	0.1 - 1.0 mm	fine	-	Medium rate	moist
9	Coarse sandstone	52	102	26	30%	70%	0.1 - 1.0 mm	fine	-	Low rate	dry
10	Coarse sandstone	52	132	86	6%	94%	< 0.1 mm	fine	-	Low rate	dry
11	Coarse sandstone	60	144	70	8%	92%	< 0.1 mm	fine	Hard filler < 5 mm	Low rate	dry
12	Coarse sandstone	40	61	64	3%	97%	0.1 - 1.0 mm	fine	Hard filler < 5 mm	Low rate	dry
13	Coarse sandstone	40	61	70	5%	95%	0.1 - 1.0 mm	fine	Soft filler < 5 mm	Medium rate	moist
14	Coarse sandstone	39	67	61	15%	85%	< 0.1 mm	fine	Hard filler < 5 mm	Medium rate	dry
15	Fine sandstone	37	68	70	5%	95%	0.1 - 1.0 mm	fine	-	Low rate	moist
16	Fine sandstone	46	67	-37	7%	93%	< 0.1 mm	fine	Hard filler < 5 mm	Low rate	dry
17	Fine sandstone	46	68	-37	4%	96%	< 0.1 mm	bit rough	-	Low rate	moist
18	Fine sandstone	44	96	107	1%	99%	< 0.1 mm	bit rough	-	Low rate	moist
19	Fine sandstone	45	96	108	3%	97%	None	fine	-	Low rate	moist
20	Mudstone	60	127	108	7%	93%	None	fine	-	Low rate	dry
21	Mudstone	47	93	88	3%	97%	< 0.1 mm	fine	-	Low rate	dry
22	Mudstone	48	96	102	8%	92%	None	fine	-	Low rate	dry

TABL 6. Rock mass class based on RMR and GSI rock mass classification system

Cross section	Rock types	Location			Discontinuity rating						RMR	GSI	Rock mass class
		S	B	RL	σ_c (MPa)	RQD (%)	spacing (cm)	Dicsontinuity condition	Ground water condition	Discontinuity orientation			
1	Coarse sandstone	40	69	49	13.47 2.3	97.54 19.5	42 10.1	23	15	-10	60	61	III Fair rock
2	Coarse sandstone	40	64	36	8.68 1.8	94.63 18.9	27 8.7	22	15	-20	42	56	III Fair rock
3	Fine sandstone	43	61	-5	1.24 1.1	98.56 19.7	56 11.3	18	15	-25	25	50	IV Poor rock
4	Fine sandstone	43	61	3	4.46 1.4	92.46 18.4	22 8.2	20	15	-25	38	55	IV Poor rock
5	Fine sandstone	47	102	80	28.3 3.6	98.85 19.8	63 11.8	24	15	-5	71	66	II Good rock
6	Fine sandstone	44	77	-71	16.2 2.5	96.95 19.4	27 8.7	21	15	-25	40	57	IV Poor rock
7	Fine sandstone	45	77	-50	2.92 1.3	90.98 18.1	20 8	20	15	-25	37	54	IV Poor rock
8	Fine sandstone	52	103	26	1.8 1.2	96.74 19.3	36 9.6	20	10	-25	35	57	IV Poor rock
9	Coarse sandstone	52	102	26	1.8 1.2	90.98 18.1	20 8	22	10	-25	34	56	IV Poor rock
10	Coarse sandstone	52	132	86	8.68 1.8	94.63 18.9	27 8.7	23	15	-25	42	58	IV Poor rock
11	Coarse sandstone	60	144	70	13.47 2.3	98.25 19.7	50 10.8	21	15	0	69	60	II Good rock
12	Coarse sandstone	40	61	64	2.92 1.3	93.02 18.5	23 8.3	20	15	-25	38	55	IV Poor rock
13	Coarse sandstone	40	61	70	1.8 1.2	73.58 14.5	10 6.8	18	15	-25	24	46	IV Poor rock

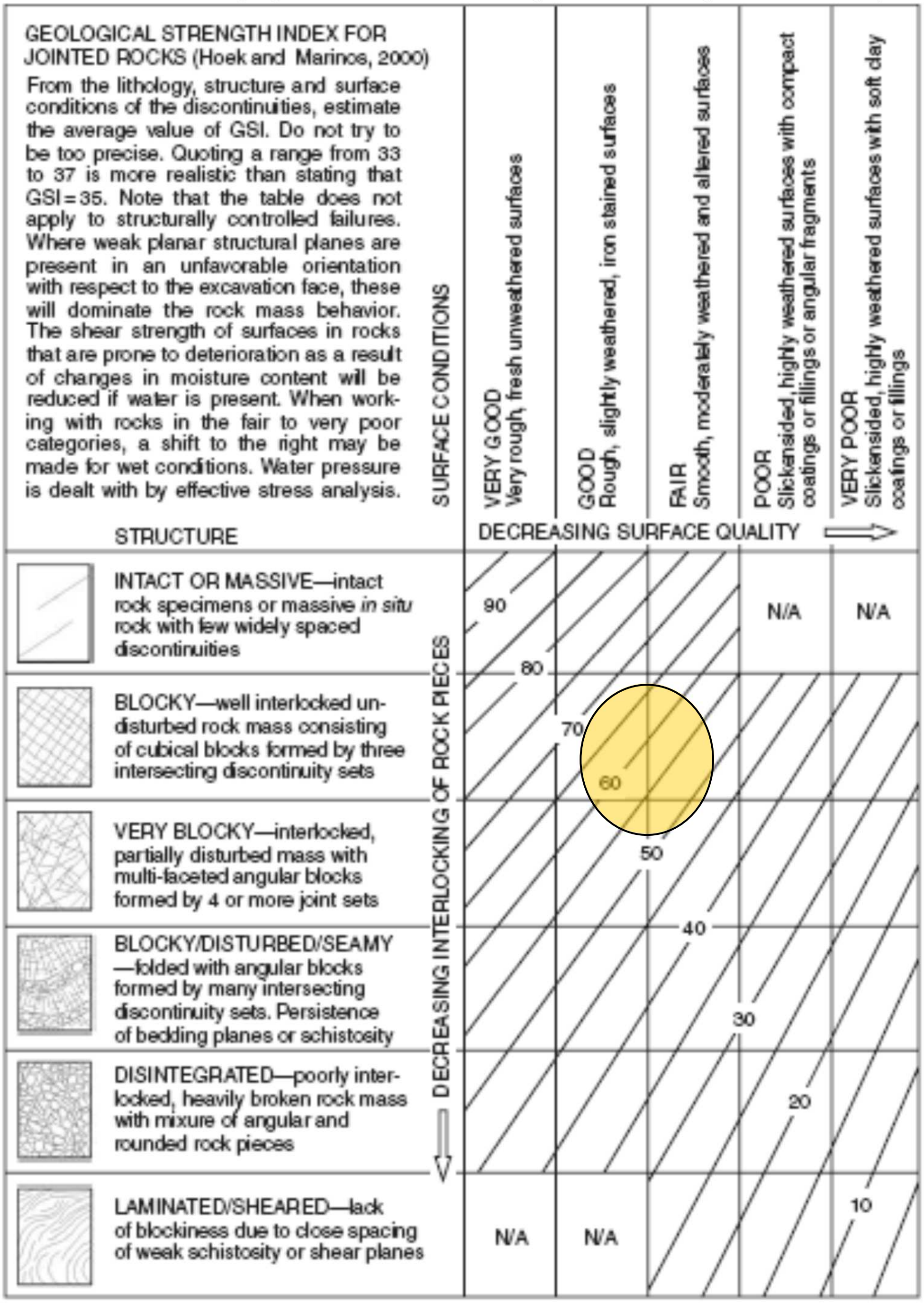
(continued)

Cross section	Rock types	Location			Discontinuity rating						RMR	GSI	Rock mass class
		S	B	RL	σ_c (MPa)	RQD (%)	spacing (cm)	Dicsontinuity condition	Ground water condition	Discontinuity orientation			
14	Coarse sandstone	39	67	61	2.92 1.3	93.57 18.6	24 8.4	19	15	-25	37	54	IV Poor rock
15	Fine sandstone	37	68	70	1.32 1.1	90.98 18.1	20 8	22	10	-40	24	55	IV Poor rock
16	Fine sandstone	46	67	-37	1.8 1.2	86.48 17.2	16 7.5	21	15	-25	37	53	IV Poor rock
17	Fine sandstone	46	68	-37	4.46 1.4	90.98 18.1	20 8	25	10	-25	37	58	IV Poor rock
18	Fine sandstone	44	96	107	28.3 3.6	98.85 19.8	63 11.8	25	10	0	70	66	II Good rock
19	Fine sandstone	45	96	108	28.3 3.6	98.56 19.7	56 11.3	24	10	0	69	65	II Good rock
20	Mudstone	60	127	108	3.57 1.3	85.46 16.9	15 7.4	20	15	-15	46	52	III Fair rock
21	Mudstone	47	93	88	1.84 1.2	98.85 19.8	63 11.8	21	15	0	69	60	II Good rock
22	Mudstone	48	96	102	1.78 1.2	71.74 14.2	10 6.8	25	15	-25	37	53	IV Poor rock

S = strip, B = block, RL = Relative Level, σ_c = Uniaxial Compressive Strength , RQD = Rock Quality Designation, RMR = Rock Mass Rating dan GSI = Geological Strength Index.

Based on the results of rock mass characterization, GSI shows that the highest value is 66 (cross-section 5 fine sandstone) and the lowest is 46 (cross-section 13 coarse sandstone), then it can be classified as good and fair rocks with the structure of relationships between grains including blocky and very blocky (**TABLE 5**).

TABLE 7. GSI values for classifying rock masses based on rock particle relationships and discontinuity conditions



DETERMINATION OF THE RELATIONSHIP BETWEEN GSI AND RMR

Hoek & Brown (1997) make an empirical equation of the relationship between determining GSI as a function of RMR_{89}, i.e.

$GSI = RMR_{89} – 5$ (1)

Equation (1) applies to RMR> 23. If RMR <23, then the equation GSI, i.e.

$GSI = RMR_{76}$ (2)

The subscript on the RMR indicates the year of manufacture for example, RMR_{89} signifies RMR was made by Bieniawski in 1989, as well as for RMR_{76}. The difference rating of RMR_{76} and RMR_{89} is in the block size parameters (space and RQD), discontinuity conditions and groundwater conditions. Rating for the block size of RMR_{76} between 8 - 50 and RMR_{89} between 8 - 40, Rating for discontinuity conditions at RMR_{76} between 0-25 and RMR_{89} between 0 - 30 and rating for groundwater conditions at RMR_{76} between 0 - 10 and RMR_{89} between 0 - 15

Hoek & Brown's empirical equation (1) and (2) were applied to the RMR with dry rock mass conditions with the groundwater conditions rating of 10 for RMR_{76} and 15 for RMR_{89} and did not take into account the general direction conditions of discontinuity. The results of this RMR are calculated from the results of calculations based on four parameters of the RMR classification system. The purpose of knowing RMR is to make a relationship between GSI and RMR.

According to the calculation of the four main parameters of the Tutupan mine RMR obtained RMR $_{(B)}$ as in **TABLE VII**. Based on the rating results of the RMR obtained the lowest value of RMR is 54 for coarse sandstone (cross-section 13) and the highest value of RMR is 75 for fine sandstone (cross-section 5 and cross-section 18).

TABLE 8. Rating of each parameter to get the RMR value of Tutupan mine

Cross section	σ_c	RQD	Spacing	Discontinuity conditions	Groundwater conditions	RMR
1	2.3	19.5	10	23	15	70
2	1.8	18.9	9	20	15	64
3	1.1	14.7	11	16	15	58
4	1.4	18.4	8	20	15	63
5	3.6	19.8	12	25	15	75
6	2.5	19.4	9	20	15	66
7	1.3	18.1	8	20	15	62
8	1.2	19.3	10	20	15	65
9	1.2	18.1	8	22	15	64
10	1.8	18.9	9	23	15	67
11	2.3	19.7	11	21	15	69
12	1.3	18.5	8	20	15	63
13	1.2	14.5	7	16	15	54
14	1.3	18.6	8	19	15	62
15	1.1	18.1	8	22	15	64
16	1.2	17.2	8	21	15	62
17	1.4	18.1	8	25	15	68
18	3.6	19.8	12	25	15	75
19	3.6	19.7	11	24	15	74
20	1.3	16.9	7	20	15	61
21	1.2	19.8	12	21	15	69
22	1.2	14.2	7	25	15	62

After this, the RMR value will be used to calculate the GSI value by equation (1; Hoek & Brown, 1997). Furthermore, the relationship between GSI according to Hoek & Brown (1997) and GSI characterization results. There are different calculation results between the GSI values according to equation (1) and the results of the characterization (**TABLE VIII).** TABLE VIII shows the results of the RMR, GSI according to Hoek & Brown (1997) and the results of the characterization.

TABLE 9. The value of Rock Mass Rating (RMR), GSI Hoek & Brown's (1997) and characterization results

RMR	GSI	GSI*)	GSI **)
70	61	65	62
64	56	59	56
58	50	53	50
63	55	58	55
75	66	70	67
66	57	61	58
62	54	57	54
65	57	60	57
64	56	59	56
67	59	62	59
69	60	64	61
63	55	58	55
54	46	49	46
62	54	57	54
64	56	59	56
62	53	57	54
68	58	63	60
75	66	70	67
74	65	69	66
61	52	56	53
69	60	64	61
62	53	57	54

*) GSI = RMR – 5 (Hoek & Brown, 1997); **) GSI = RMR – 8

By making a graph of the relationship of RMR value, GSI characterization results, GSI according to Hoek & Brown (1997) and the correction result GSI will be clearly seen when equation (1) was applied, there appear 3 to 4 values deviation from the result of GSI characterization in soft rocks.

The difference of value between GSI according to Hoek & Brown (1997) with GSI measurement is 3 and 4, therefore to calculate GSI from RMR is to reduce it by 8 scores, so the Hoek & Brown equation changes from

$$GSI = RMR - 5 \quad (3)$$

to be

$$GSI = RMR - 8 \quad (4)$$

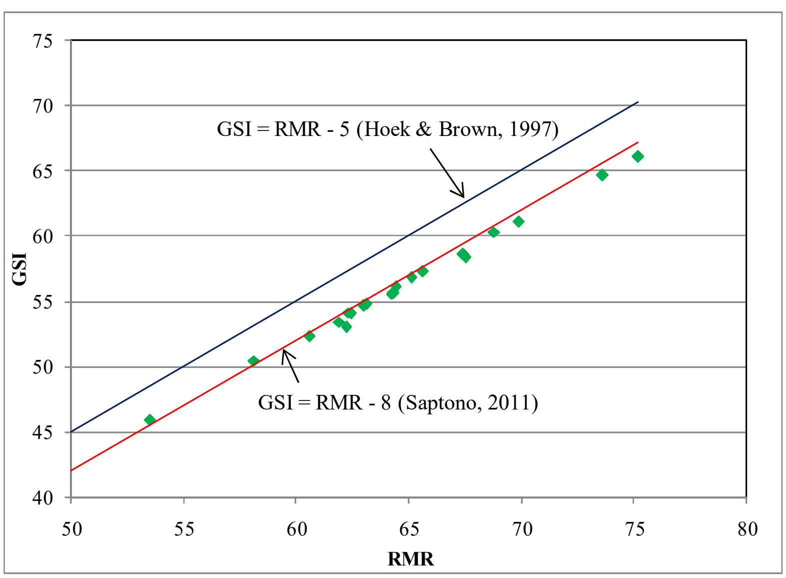


FIGURE 2. Comparison between the corrected GSI equation and Hoek & Brown GSI (1997) equation

CONCLUSION

The main contributions in this paper are summarized as follows:

1. The rock mass classification at the Tutupan site shows that RMR ranged from 24 (cross-section of 13 types of coarse sandstone) to 71 (cross-section of 5 types of fine sandstone) and the rest fall in poor to good rock mass categories. In terms of GSI, the majority of the rock masses have fair to good GSI (46 to 66)
2. The GSI equation obtained to corrects the Hoek & Brown (1997) equation to be applied in sediment rock masses in coal mines, i.e.
   GSI = RMR – 8

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