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TUNNEL EVALUATION IN CROCKER FORMATION BY GEOLOGICAL STRENGTH INDEX (GSI) SYSTEM: A CASE STUDY

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ABSTRACT

This study was conducted to determine the value of Geological Strength Index (GSI), to predict rock mass properties, very unfavourable discontinuities combination and tunnel support pressure for rock bolts or shotcrete and to determine the suitability of GSI for a tunnel in Crocker Formation. Engineering geological mapping and discontinuity survey was done along the tunnel face as well as rock sampling. GSI values and the disturbance factor were obtained from field observation on the tunnel face. Point load and dry density test was conducted to determine the Uniaxial Compressive Strength (UCS) and unit weight, respectively. The rock mass properties, kinematic analysis and limit equilibrium analysis was used to determine the factor of safety (F.O.S) and pressure to stabilise the tunnel. The rock mass was characterised by 94.88 MPa UCS, 0.024 MN/m3 unit weight, widely space and high persistency. The GSI value is 50 with 0.8 disturbance factor. The cohesion, friction angle and tensile strength are 3.671 MPa, 25.20° and 0.056 MPa respectively. The friction angle was reduced by 5° due to lower shear strength of bedding plane. There are eight possibilities of discontinuities combinations on tunnel crown that have F.O.S lower than 2 and combination of joints 2, 4 and 6 has the maximum wedge volume of 28.37 m3. The maximum support pressure of rock bolts or shotcrete for F.O.S of 2 at the tunnel crown is 0.04 MN. The high F.O.S value may have been due to the overestimation of friction angle and cohesion of discontinuity plane. Then, this study shows that GSI system is unsuitable for the tunnel in study area which behave as anisotropic and structurally controls rock mass, but if needed, the values of rock mass properties, discontinuities combination and support pressure can be used for tunnel design.

KEYWORDS

Geological Strength Index (GSI), tunnel, Crocker Formation, limit equilibrium analysis.

1. INTRODUCTION

This study was conducted along a tunnel in Tenom, Sabah (Figure 1) as shown in Photo 1. The study area is underlain by the Crocker Formation of Late Eocene to Late Early Miocene ages and consists of tectonically disturbed thick amalgamated sandstone with thin shale layers (Photo 2) [1]. The objectives of this study are to determine the value of Geological Strength Index (GSI), to predict the rock mass properties, very unfavourable discontinuities combination, tunnel support pressure for rock bolts or shotcrete and to determine the suitability of GSI system for the tunnel in study area.

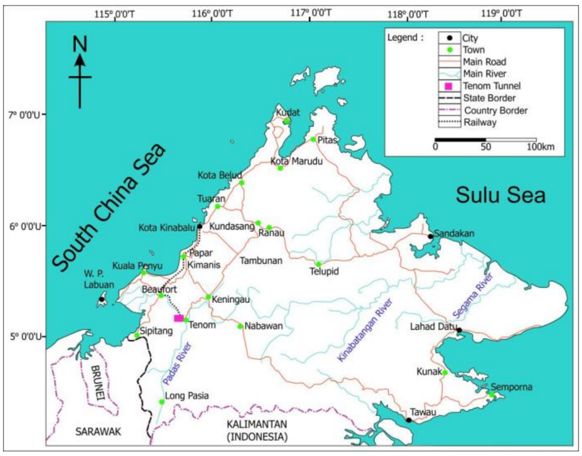

Figure 1: Location of Tenom Tunnel

Photo 1: Entrance of Tenom Tunnel. Photo direction – east southeast (ESE) to west northwest (WNW)

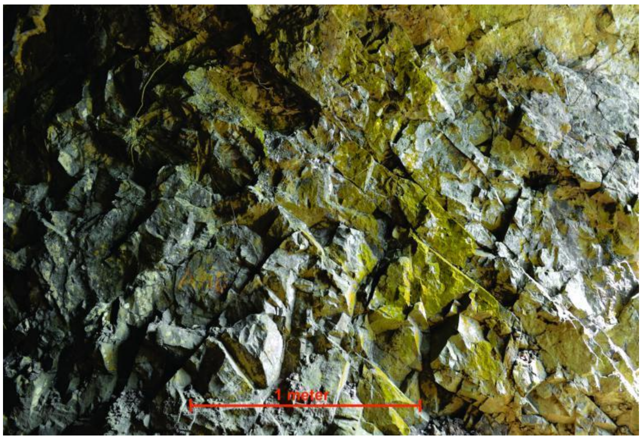

Photo 2: Amalgamated thick sandstone unit of Crocker Formation

Geological Strength Index (GSI) was introduced as an extension from Hoek-Brown criterion [2]. The index and its use for the Hoek-Brown failure criterion was further developed but it was still for hard rock system which generally equivalent to RMR [3-6]. While Evert Hoek and Paul Marinos were dealing with incredibly difficult materials encountered in tunnelling in Greece, they developed the GSI system for poor quality rock mass [7]. Although GSI system is only suitable for homogenous rock masses, it was applied in heterogeneous rock masses such as Flysch, until it was revised by Marinos [8,9].

GSI has been applied continuously in various major tunnel excavations around the world especially in heterogeneous rock masses such as flysch. One of the major applications of this system was done during the tunnel excavation for the Egnatia Highway in Northern Greece [10]. Another major application was done for the Chenani-Nashri Tunnel which is the longest road tunnel in India [11].

Study on the application of GSI for the tunnel in Crocker Formation has never been attempted thus this study has been conducted to determine the GSI value, to predict rock mass properties, very unfavourable discontinuities combination and tunnel support pressure for rock bolts or shotcrete and to determine the suitability of GSI for the tunnel in the study area.

2. METHODOLOGY

Lithological mapping, surface mapping and discontinuity survey were conducted to obtain quantitative description of discontinuities as well as rock sampling [12]. A researcher has been proposed to be using GSI charts for Crocker formation based on the surface condition together with the structure and composition of the tunnel face [9, 13,14]. The disturbance factor of 0.8 was obtained by field observation on the tunnel face [15]. Laboratory study was done to determine the Uniaxial Compressive Rock mass properties of the tunnel were determined using RocLab software where the input parameters are UCS of intact rock, GSI value, disturbance factor, and Hoek-Brown material constant [20]. RocLab uses the Hoek-Brown and Mohr-Coulomb criteria to empirically estimate the rock mass properties (cohesion, friction angle and tensile strength) based on the given parameters [15]. Result of rock mass properties were then used as input parameters into Unwedge software to determine the very unfavourable discontinuities combinations [21]. Wedge failure is the potential mode of failure based on kinematic analysis and limit equilibrium analysis. Unwedge software is based on the Block Theory [22]. Support pressure required for tunnel support by using rock bolts or shotcrete was calculated based on design factor of safety of 2 which is sufficient to avoid failure caused by the vibrations from passing train [8].

3. RESULTS AND DISCUSSION

The GSI value from field observation are 50 after being reduced from 55 as suggested by a researcher because the tunnel consists of thick amalgamated sandstone with thin shale layers instead of thick amalgamated sandstone with thin siltstone layers (Figure 2 and Photo 3) [23]. This value was obtained by identifying the surface condition and the type of the tunnel wall [14]. Based on the study, the surface condition of the tunnel wall is good with structure and composition of type III. The tunnel geometry and discontinuity orientation were shown in Table 1. Table 2 shows the result of laboratory testing, parameters and derived rock mass properties from related schemes and software. The disturbance factor was chosen as 0.8 because blasting and hammering were used in the excavation method [15]. Friction angle was reduced by 5° due to shear strength of bedding plane.

The result of Unwedge software was presented in Table 3. There are eight out of the twenty possible discontinuities combinations on tunnel crown that have F.O.S lower than 2.0 with a maximum wedge volume of 28.37 m^3 formed from combinations of joint 2, 4 and 6 (Figure 3). The wedges were formed by the combination of at least 3 discontinuities such as bedding and joint planes. The F.O.S value for crown wedges was nil because the wedge was practically hanging without support and might have failed immediately after excavation previously. The wedge blocks at the crown might have failed over the years and caused the shape of the crown to change from its initial shape. To achieve F.O.S of 2, rock bolts or shotcrete can be installed on the tunnel crown with maximum support pressure of 0.04 MN.

The high values of F.O.S for left and right wall might have been because the overestimation of friction angle and cohesion for individual discontinuity plane. Based on the result, rock mass properties obtained from GSI system should not be applied for individual discontinuity plane due to the rock mass properties do not represent individual discontinuity plane but the rock mass as the whole.

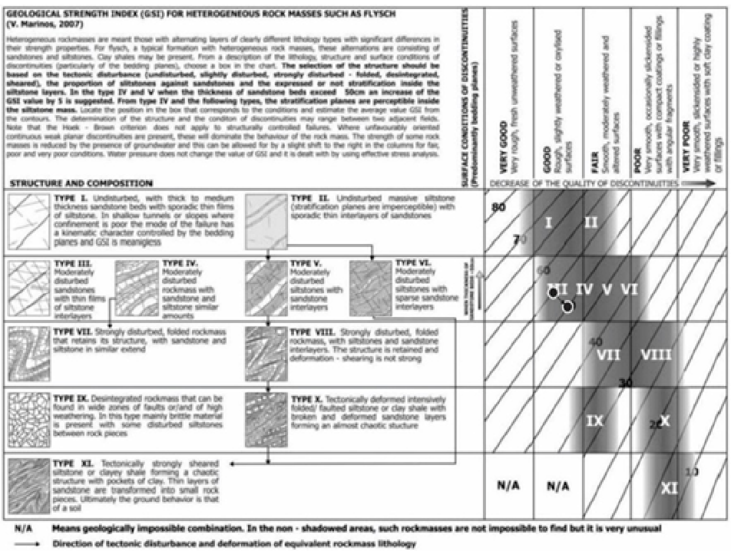

Figure 2: GSI chart and value for rock mass (black dot) [9]

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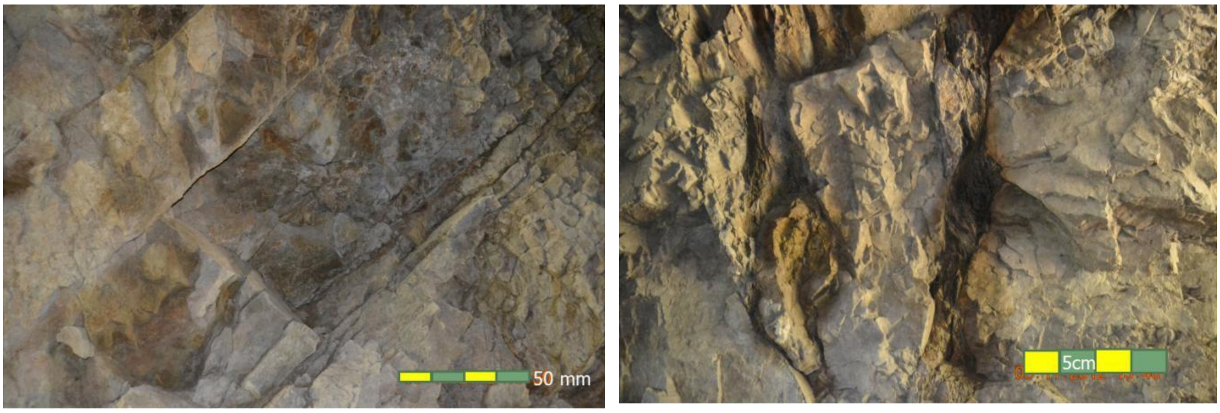

Photo 3: Amalgamated thick sandstone unit of Crocker Formation

Table 1: Tunnel geometry and discontinuity orientation

Tunnel	Values	Discontinuity	Strike/Dip
Length	42.69 m	Joint 1, J1	30/60
Width	4.4 m	Joint 2, J2	185/55
Height	4.6 m	Joint 3, J3	215/70
Right wall	87°	Joint 4, J4	87/42
Left wall	87°	Joint 5, J5	2/24
		Joint 6, J6	277/86

Table 2: Parameters and rock mass properties

Parameters / Properties	Values
GSI	50
Disturbance factor	0.8
Unit Weight (MN/m^3)	0.024
Hoek-Brown material constant (m_i)	10
UCS (MPa)	94.88
Cohesion (MPa)	3.67
Friction angle for bedding (°)	20.2
Friction angle for joint (°)	25.2
Tensile strength (MPa)	0.056

Table 3: Predicted discontinuities combinations which contain F.O.S below 2 including maximum support pressure needed and maximum wedge volume

Combination	Wedges on tunnel section	F.O.S	Max. support pressure (MN)	Max. wedge volume (m^3)
J1,J2,J6	Floor	Stable	0.00	2.071
	Left	1183.134	0.00	0.227
	Right	3024.801	0.00	0.227
	Crown	0.000	0.02	2.071
J1,J2,J3	Floor	Stable	0.00	0.092
	Left	6780.508	0.00	1.944
	Right	1196.101	0.00	1.944
	Crown	0.000	0.01	0.092
J1,J2,J5	Floor	Stable	0.00	0.011
	Left	812.480	0.00	18.362
	Right	1231.028	0.00	18.362
	Crown	0.000	0.00	0.011
J1,J3,J4	Floor	Stable	0.00	0.125
	Left	2874.700	0.00	13.102
	Right	452.463	0.00	13.102
	Crown	0.000	0.01	0.125
J2,J4,J5	Floor	Stable	0.00	0.013
	Left	12264.928	0.00	13.469
	Right	371.609	0.00	13.469
	Crown	0.000	0.00	0.013
J2,J4,J6	Floor	Stable	0.00	28.370
	Left	574.165	0.00	0.297
	Right	3024.801	0.00	0.297
	Crown	0.000	0.04	28.370
J3,J4,J5	Floor	Stable	0.00	1.288
	Left	1105.018	0.00	11.379
	Right	371.609	0.00	11.379
	Crown	0.000	0.01	1.288
J3,J4,J6	Floor	Stable	0.00	24.068
	Left	544.096	0.00	0.625
	Right	2049.625	0.00	0.625
	Crown	0.000	0.04	24.068

In this study, GSI of class III and IV are characterized as a purely anisotropic and anisotropic rock masses, respectively [23]. And, it is representing structurally controls cut/ slopes faces. GSI is also suitable for isotropic rock cut/ slope faces or rock mass controls only[9]. But, occurrences of wedge failures by the combination of discontinuities shows that the rock mass in the study area are anisotropic and structurally controls rather than structurally controlled by rock mass controls.

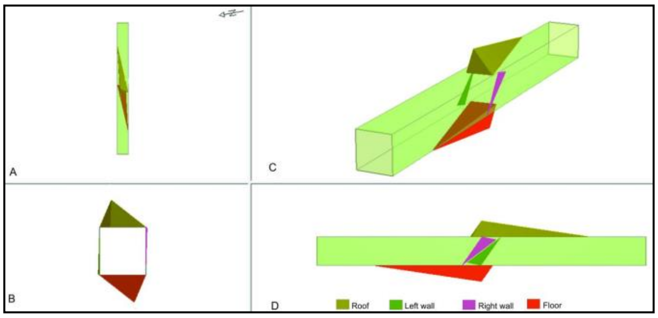

Figure 3: Blocks that can be formed from combination of J2J4J6 in four views.

A – Top view; B – Front view; C – 3D view; D – Side view.

4. CONCLUSION

It can be concluded that the GSI value for Crocker Formation for this case study is 55, cohesion, friction angles and tensile strength are 3.67MPa, 25.2^{o} and 0.056MPa, respectively, very unfavourable discontinuities combination is J2J4J6, the support pressure for rock bolts and shotcrete are 0.04MN and GSI system is not suitable for the tunnel in study area, but the values of rock mass properties, discontinuities combination and support pressure can be used for tunnel design if needed.

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