PREDICTION OF ROCK MASS PROPERTIES, TUNNEL STABILITY AND SUPPORT PRESSURE BY GEOLOGICAL STRENGTH INDEX (GSI) IN CROCKER FORMATION: A CASE STUDY

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ABSTRACT

This study was conducted along a tunnel in Crocker Formation. The objectives of this study are to determine the value of Geological Strength Index (GSI) and to predict rock mass properties, very unfavourable discontinuities combination and tunnel support pressure for rock bolts or shotcrete for the tunnel. Engineering geological mapping, rock sampling and estimation of GSI values and the disturbance factor were conducted along the tunnel faces. Laboratory analysis includes Point load and dry density test and data analysis consists of kinematic analysis and limit equilibrium analysis. The rock mass was characterised by 94.88 MPa UCS, 0.024 MN/m³ unit weight, widely space and high persistency of discontinuities. The GSI value is 50 with 0.8 disturbance factor. The cohesion, tensile strength and friction angle are 3.671 MPa, 0.056 MPa and 25.20°, respectively. There are eight possibilities of discontinuities combinations on tunnel roof that have factor of safety (F.O.S) lower than 2 and combination of joints 2, 4 and 6 has the highest maximum wedge volume of 28.37 m³. The maximum support pressure of rock bolts or shotcrete for F.O.S of 2 is 0.04 MN. The individual discontinuity plane has been identified to overestimate friction angle and cohesion values, then the GSI system should be applied in homogeneous or isotropic and not in structurally controlled rock masses.

1. INTRODUCTION

This study was conducted along a tunnel in Tenom, Sabah (Figure 1) as shown in figure 1a. 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 (figure 1b) [1]. The objectives of this study are to determine the value of Geological Strength Index (GSI) and to predict the rock mass properties, very unfavourable discontinuities combination and tunnel support pressure for rock bolts or shotcrete for the tunnel in Crocker Formation.

Figure 1: Location of Tenom Tunnel.

Geological Strength Index (GSI) was introduced by a researcher as an extension from Hoek-Brown criterion and evolved until but it was still for hard rock masses which generally equivalent to RMR [2-4]. GSI has been applied continuously in various major tunnel excavations around the world especially in heterogeneous rock masses such as flysch [5]. One of the major applications of this system was done by some researcher for a tunnel of Egnatia Highway in Northern Greece [6]. Another major application was done for the Chenani-Nashri Tunnel which is the longest road tunnel in India [7]. This study has been conducted in the study area because the application of GSI has never been attempted for the tunnel in Crocker Formation.

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

Figure 1b: Amalgamated thick sandstone unit of Crocker Formation.
2. METHODOLOGY

Discontinuity survey was conducted to obtain quantitative description of discontinuities as well as rock sampling. GSI values were determined by using the charts by a researcher [8,9]. The disturbance factor was obtained by field observation on the tunnel face [10]. Laboratory study was done to determine the Uniaxial Compressive Strength (UCS) via point load test with a conversion factor of 22 and unit weight via dry density test [11,12]. The final UCS, Hoek-Brown material constant and density values of intact rock were obtained via weighted average method [5]. Hoek-Brown material constant (m) for sandstone is 17 as suggested values [13].

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 [14]. RocLab uses the Hoek-Brown and Mohr-Coulomb criteria to empirically estimate the rock mass properties (cohesion, friction angle and tensile strength of rock mass) based on the given parameters [10]. Result of rock mass properties were then used as input parameters into Unwedge software to determine the very unfavourable discontinuities combinations [15]. Wedge failure is the most potential failure based on kinematic analysis and limit equilibrium analysis. The calculations done by the software were based on the Block Theory [16]. Support pressure required for tunnel support by using rockbolts 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.

3. RESULTS AND DISCUSSION

The GSI value from field observation for the study area is 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) [17]. This value was obtained by identifying the surface condition and the type of the tunnel wall [18]. Based on this 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 [10]. Friction angle was reduced by 5° due to shear strength of bedding plane.

The result of limit equilibrium analysis via Unwedge was presented in Table 4 [15]. There are eight out of the twenty possible discontinuities combinations on tunnel roof that have F.O.S lower than 2 with a maximum wedge volume of 28.373 m³ formed from combination of joint 2, 4 and 6 (Figure 3). The wedges were formed by the combination of at least 3 discontinuities. The F.O.S value for roof of wedges was nil because the wedge was practically hanging without support and might have failed immediately after excavation. The wedge blocks at the crown might have failed over the years and altering their shape. The overestimation of friction angle and cohesion for individual discontinuity plane has been causing high values of F.O.S for left and right wall of the tunnel. This might be caused by the rock mass properties obtained from GSI system do not represent individual discontinuity plane but the rock mass as a whole, where the GSI is only suitable for isotropic or homogenous rather than structurally controlled rock masses [19]. To achieve F.O.S of 2, rock bolts or shotcrete can be installed on to the tunnel roof with maximum support pressure of 0.04 MN.

Table 1: Tunnel geometry and discontinuity orientation.

| Parameters / Properties | Values |
|-------------------------|--------|
| GSI                     | 50     |
| Disturbance factor      | 0.8    |
| Unit Weight (MN/m²)     | 0.024  |
| Hoek-Brown material constant (m) | 17 |
| 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 4: Predicted discontinuities combinations which contain F.O.S below 2 including maximum support pressure needed and maximum wedge volume.

| Combination | Type of wedges | F.O.S | Max. support pressure (MN) | Max. wedge volume (m³) |
|-------------|----------------|-------|----------------------------|------------------------|
| J1, J2, J6  | Left 1183.134 | 0.00  | 2.071                      | 24.068                 |
| Left 3024.801 | 0.00  | 2.071 |
| Right 3024.801 | 0.00  | 2.071 |
| Roof 0.000 | 0.02  | 2.071 |
| J1, J2, J3  | Left 6780.508 | 0.00  | 0.092                      | 0.297                  |
| Right 1196.101 | 0.00  | 1.944 |
| Roof 0.000 | 0.01  | 0.092 |
| Roof 0.000 | 0.01  | 0.092 |
| J1, J2, J5  | Left 8124.801 | 0.00  | 18.362                     | 28.370                 |
| Right 1231.028 | 0.00  | 18.362 |
| Roof 0.000 | 0.00  | 0.013 |
| J1, J3, J4  | Left 2874.700 | 0.00  | 13.102                     | 13.469                 |
| Right 452.463 | 0.00  | 13.102 |
| Roof 0.000 | 0.01  | 0.125 |
| J2, J4, J5  | Left 12264.928 | 0.00  | 13.469                     | 13.469                 |
| Right 371.609 | 0.00  | 13.469 |
| Roof 0.000 | 0.00  | 0.013 |
| J2, J4, J6  | Left 574.165 | 0.00  | 0.297                      | 0.297                  |
| Right 3024.801 | 0.00  | 0.297 |
| Roof 0.000 | 0.04  | 28.370 |
| J3, J4, J5  | Left 1105.018 | 0.00  | 11.379                     | 11.379                 |
| Right 371.609 | 0.00  | 11.379 |
| Roof 0.000 | 0.01  | 1.288 |
| J3, J4, J6  | Left 544.096 | 0.00  | 0.625                      | 0.625                  |
| Right 2049.625 | 0.00  | 0.625 |
| Roof 0.000 | 0.04  | 24.068 |

Figure 2: GSI chart (Marinos, 2007) and value for rock mass (red dot).

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.

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4. CONCLUSION & RECOMMENDATION

It can be concluded that the GSI value for Crocker Formation for this case study is 50, rock mass properties are 3.67, 0.065 MPa and 25.20° of cohesion, tensile strength and friction angle, respectively, very unfavourable discontinuities combination is J2J4J6 and the support pressure required for rock bolts or shotcrete is 0.04 MN.

GSI can be a good alternative for tunnel study due to its simplicity and accuracy in estimating the rock mass properties provided with sufficient data and tools. However, the GSI should be applied in homogeneous or isotropic and not in structurally controlled rock masses.

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