Stability Assessment of Limestone Cave: Batu Caves, Selangor, Malaysia
(Penilaian Kestabilan Gua Batu Kapur: Batu Caves, Selangor, Malaysia)

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ABSTRACT

The limestone hill of Batu Caves is slowly being turned into a recreation park for slope climbing, base jumping and cave exploring. Quantitative assessment on the stability of the cave is essential to ensure the safety of tourists and visitors. The aim of this study was to quantitatively assess the stability of Gua Damai, Batu Caves, Selangor, Malaysia by using the Q system for rock mass classification, together with other factors such as cave width and thickness of the cave roof. The stability of the limestone cave wall was evaluated using Slope Mass Rating (SMR). A discontinuity survey conducted along the slopes beneath the opening of the cave showed that the rock mass comprised of four major joint sets labeled as J1, J2, J3, and J4 with the dip directions and angles of 110°/73°, 325°/87°, 243°/39° and 054°/30°, respectively. The result of kinematic analysis showed that the dip direction/dip angle of a potential wedge failure was 051°/59°. By referring to the ratio of cave roof thickness with cave width, the results showed that the cave is stable. Based on the relationship between Q system and the cave width, the stabilities of Section 4 of Gua Damai is stable while Section 1, 2, 3, 5, 6, 7 and 8 require supports. Based on SMR, the cave walls stability at Portion c, d, and f were not stable while Portion a, b, e and g were stable. Overall, the most stable part of the cave is Section 4 followed by Sections 5 and 2. Sections 1, 3 and 8 are moderately stable while Sections 6 and 7 have poor stability.

Keywords: Cave stability assessment; limestone; Slope Mass Rating (SMR); Q system

INTRODUCTION

Geological hazards such as landslides, rockfalls, subsidence, sinkholes and the collapse of limestone bedrock are common engineering problems in tropical countries due to the quick process of dissolution by acidic rainwater. Hatzor et al. (2002) suggested that the collapse of the cave he studied was caused by failure of the rock mass, movement of the cave walls and roof of the cave. However, the hazards of limestone caves are difficult to estimate. Waltham (2002) and Waltham and Fookes (2003) assessed the stability of a limestone cave by using Q System and the width of cave and also suggested that the cave is classified as stable when the thickness of the roof of the cave is more than 70% of the width of the cave. Local researchers such as Abdul Ghani and Goh (2015), Goh et al. (2016a, 2016b, 2016c, 2015a, 2015b), Norbert et al. (2015), Muhammad Fahmi et al. (2016), Tan (2006, 2001) were more focused on the stability of slopes of limestone hills, rock falls and rock material strengths. There are less researches and studies on the stability of limestone caves in Malaysia.

The aim of this study was to assess quantitatively, the stability of the cave wall of Gua Damai, Batu Cave
in Selangor using slope mass rating (SMR) and the cave stability using the Q system for rock mass classification, cave width and thickness of the cave roof.

MATERIALS AND METHODS

GEOLOGICAL SETTING

Batu Caves, Selangor is located 13 km to the north of Kuala Lumpur (Figure 1). Gobbett and Hutchison (1973) reported that the limestone was crystalline, greyish to milky white, thick bedded, stripped marble, saccharoidal dolomite and pure calcatic limestone. The geology (Figure 2) of Kuala Lumpur area consists of sedimentary rocks ranging in age from Middle-Upper Silurian to Mesozoic or younger overlying the older Hawthornden Formation and the Kuala Lumpur Limestone Formation (Gobbett 1965). The limestone in Gua Damai is Silurian in age and is part of Kuala Lumpur Limestone Formations. Kuala Lumpur Limestone Formation was overlying by a younger metasedimentary Kenny Hill Formation composed of quartzite and phylite. Hawthornden Schist Formation composed of interbedded fine grained with dark coloured of rock sequence due to the presence of carbon material and pyrite. The oldest rock formation at Kuala Lumpur is Dinding Schist with the age of Cambrian to Ordovician composing quartz mica schist, calc-silica and schistos conglomerate (Gobbett 1965).

ASSESSMENT OF CAVE STABILITY

The Q value is calculated from the rock mass rating (RMR), as suggested by Barton (1995) using (1):

\[ RMR = 15 \log Q + 50 \]  

The stability of limestone cave was classified based on recommendations of Waltham (2002) and Waltham and Fookes (2003). The Q value and width of limestone cave width were used to assess the stability (Figure 3). Waltham (2002) and Waltham and Fookes (2003) also suggested that the cave is stable when the thickness of the roof of the cave are more than 70% of the width of the cave.

ASSESSMENT OF CAVE WALL STABILITY BY USING SLOPE MASS RATING (SMR) METHOD

The slope mass rating method was proposed by Romana (1995) and used to assess the stability of cave wall. This method comprised of the following components: Uniaxial compressive strength (UCS); Rock quality designation (RQD); Discontinuities spacing; Conditions of discontinuities; Ground water condition; Adjusting factors for joints (F1, F2, F3); and Adjusting factor for excavation (F4).

The uniaxial compressive strength (UCS) of rock material was determined based on the recommendations of the International Society for Rock Mechanics (1985, 1981). The value of respective components of (b), (c), (d) and

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**Figure 1.** The location of study area in Peninsular Malaysia, Malaysia
(d) were determined from scanline discontinuity survey, following suggestions of Ibrahim Komoo dan Ibrahim Abdullah (1983). F1 was the rating for considering the difference of dip direction between joints and slope face. F2 was the rating of dip angle of the respective joint. F3 was the rating for considering the difference of dip angle between joints and slope face. The values of respective components of (a), (b), (c), (d) and (e) are rated based on Romana’s (1995) suggestions. The total rating, RMR, was (Bieniawski 1989) determined as:
\[ \text{RMR}_b = \text{Rating (a)} + \text{Rating (b)} + \text{Rating (c)} + \text{Rating (d)} + \text{Rating (e)} \quad (2) \]

The rating for SMR was determined based on (3) as suggested by Romana (1995):

\[ \text{SMR} = \text{RMR}_b + (F_1 \times F_2 \times F_3) + F_4 \quad (3) \]

RESULTS AND DISCUSSION

A total of 200 discontinuities readings were obtained for the slopes beneath the cave (Figure 4). The cave was divided into 8 sections and labelled as Sections 1, 2, 3, 4, 5, 6, 7 and 8 (Figure 5). The cave wall was divided into seven portions which were Portions a, b, c, d, e, f and Portion g according to the orientation of the wall (Figure 5). Discontinuity survey show that the slope is composed of four (4) major joint sets which are J1, J2, J3, J4 with the dip direction and angle of 110°/73°, 325°/87°, 243°/39° and 054°/30°, respectively (Figure 6). The orientations of major joint sets are exhibited in Table 1.

The average value of uniaxial compressive strength (UCS) of limestone rock was 30.5 MPa, classified as moderate strong based on classification of International Society for Rock Mechanics (1981). The Rock Quality Designation (RQD) value for the limestone slope is 84.8%. Table 2 exhibits the summary of Q ratings for the respective Sections 1, 2, 3, 4, 5, 6, 7 and 8 of Gua Damai, Batu Caves, Selangor, Malaysia. The rating for RMR was 66. The classification of rock mass rating (RMR) suggested by Bieniawski (1989) for this limestone cave were from fair to good rock mass with the rating of 54 to 66.

The stability assessment based on relationship between Q system ratings and the cave width according to Waltham (2002) and Waltham and Fookes (2003) shows that the cave
at Section 4 is stable while the cave in Sections 1, 2, 3, 5, 6, 7 and 8 require support (Figure 7). However, the sections of cave that require support are still in a stable condition because of the formation of thick limestone pillars in the middle of the cave that support the cave roof (Figure 8). The ratio of cave roof thickness with cave width was at the range of 2.5-4.0 (Figure 9). This indicated that the cave was stable whereby the ratios were more than 0.7 and the stability were increasing from center of the cave to the wall. This is because the cave was wider and higher in the middle of the cave and smaller near to the cave walls as shown in Figure 10. The higher the cave, the thinner will be the cave roof. This cause lower load and reduces material strength.

<table>
<thead>
<tr>
<th>Joint sets</th>
<th>Orientation (°)</th>
<th>Spacing (m)</th>
<th>Average Persistence (m)</th>
<th>Aperture</th>
<th>Roughness</th>
<th>Water Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1</td>
<td>110/73</td>
<td>0.98</td>
<td>1.79</td>
<td>very narrow</td>
<td>rough</td>
<td>dry</td>
</tr>
<tr>
<td>J2</td>
<td>325/87</td>
<td>1.14</td>
<td>1.60</td>
<td>very narrow</td>
<td>rough</td>
<td>dry</td>
</tr>
<tr>
<td>J3</td>
<td>243/39</td>
<td>0.45</td>
<td>1.03</td>
<td>tight</td>
<td>rough</td>
<td>dry</td>
</tr>
<tr>
<td>J4</td>
<td>054/30</td>
<td>0.36</td>
<td>2.12</td>
<td>extreme narrow</td>
<td>rough</td>
<td>dry</td>
</tr>
</tbody>
</table>

TABLE 1. Major Joint sets characteristic at Gua Damai, Batu Caves, Selangor, Malaysia

<table>
<thead>
<tr>
<th>Section</th>
<th>Cave width (m)</th>
<th>RMR&lt;sub&gt;b&lt;/sub&gt;</th>
<th>RMR</th>
<th>RMR classification</th>
<th>Q-value</th>
<th>Q-System classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.8</td>
<td>66</td>
<td>54</td>
<td>fair</td>
<td>1.85</td>
<td>poor</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>66</td>
<td>56</td>
<td>fair</td>
<td>2.51</td>
<td>poor</td>
</tr>
<tr>
<td>3</td>
<td>4.2</td>
<td>66</td>
<td>54</td>
<td>fair</td>
<td>1.85</td>
<td>poor</td>
</tr>
<tr>
<td>4</td>
<td>2.5</td>
<td>66</td>
<td>66</td>
<td>fair</td>
<td>1.85</td>
<td>poor</td>
</tr>
<tr>
<td>5</td>
<td>12.6</td>
<td>66</td>
<td>66</td>
<td>good</td>
<td>11.66</td>
<td>good</td>
</tr>
<tr>
<td>6</td>
<td>10.6</td>
<td>66</td>
<td>54</td>
<td>fair</td>
<td>1.85</td>
<td>poor</td>
</tr>
<tr>
<td>7</td>
<td>12.8</td>
<td>66</td>
<td>56</td>
<td>fair</td>
<td>2.51</td>
<td>poor</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>66</td>
<td>54</td>
<td>fair</td>
<td>1.85</td>
<td>poor</td>
</tr>
</tbody>
</table>

TABLE 2. Q values and classification system calculated from RMR value based on joint orientations for Gua Damai, Batu Caves, Selangor, Malaysia

Source: Modified from Waltham (2002) and Waltham and Fookes (2003)

FIGURE 7. The stability assessment of cave based on Q system and cave width for Gua Damai, Batu Caves, Selangor, Malaysia. The diagram shows that section 4 is stable while Section 1, 2, 3, 5, 6, 7 and 8 require support

FIGURE 8. The presence of limestone pillars in the middle of cave act as support and prevent collapse of cave roof

FIGURE 9. Contour map of the ratio of cave roof thickness with cave width for Gua Damai, Batu Caves, Selangor, Malaysia. The higher the ratio, the more stable will be the cave. This indicated that the cave is stable where by the ratios are more than 0.7
The results of the assessment on the walls of the cave based on Slope Mass Rating, SMR (Romana 1985) are exhibited in Table 3. The cave walls at Portions c, d and f are not stable while the walls of Portions a, b, e and g are stable. Portions of wall which are not stable plane result from the fact that the orientation of the respective slope face of the cave wall is parallel to the wedge failure plane (051°/59°). Therefore, the walls in Portions c, d and f are potentially having wedge failure with the probability of failure of 0.6.

CONCLUSION

Figure 11 shows the final stability of cave for Gua Damai, Batu Caves, Selangor, Malaysia. Based on the Q system and the cave width, Sections 4 and 8 of Gua Damai are stable while Sections 1, 2, 3, 5, 6 and 7 required supports. Based on SMR, the cave walls at Portions c, d and f are not stable while Portions a, b, e and g are stable. Overall, the most stable parts of the cave are Section 4 followed by Sections 5 and 2. Sections 1, 3 and 8 are moderate stable while Sections 6 and 7 have poor stability.
Table 3. Stability of cave walls based on SMR classification system, Romana (1985) for Gua Damai, Batu Caves, Selangor, Malaysia

<table>
<thead>
<tr>
<th>Portion of cave wall</th>
<th>Orientation of cave wall (°)</th>
<th>RMRb</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>Failure mode</th>
<th>SMR</th>
<th>Stability</th>
<th>Probability of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>138/81</td>
<td>66</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>none</td>
<td>66</td>
<td>stable</td>
<td>0.2</td>
</tr>
<tr>
<td>b</td>
<td>100/68</td>
<td>66</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>none</td>
<td>66</td>
<td>stable</td>
<td>0.2</td>
</tr>
<tr>
<td>c</td>
<td>55/71</td>
<td>66</td>
<td>1.00</td>
<td>1.00</td>
<td>-60</td>
<td>+15</td>
<td>wedge (51°/59°)</td>
<td>21</td>
<td>unstable</td>
<td>0.6</td>
</tr>
<tr>
<td>d</td>
<td>14/83</td>
<td>66</td>
<td>0.85</td>
<td>1.00</td>
<td>-60</td>
<td>+15</td>
<td>wedge (51°/59°)</td>
<td>30</td>
<td>unstable</td>
<td>0.6</td>
</tr>
<tr>
<td>e</td>
<td>300/77</td>
<td>66</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>none</td>
<td>66</td>
<td>stable</td>
<td>0.2</td>
</tr>
<tr>
<td>f</td>
<td>336/83</td>
<td>66</td>
<td>1.00</td>
<td>1.00</td>
<td>-60</td>
<td>+15</td>
<td>wedge (51°/59°)</td>
<td>21</td>
<td>unstable</td>
<td>0.6</td>
</tr>
<tr>
<td>g</td>
<td>256/64</td>
<td>66</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>none</td>
<td>66</td>
<td>stable</td>
<td>0.2</td>
</tr>
</tbody>
</table>

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