Deformation Modulus and Strength Parameters of Rock Mass of Maddhapara Granite Mine of Bangladesh Using Geological Strength Index

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Abstract

The rock mass strength properties and modulus of deformation of the Maddhapara Granite Mine (MGM) were estimated and evaluated with Geological Strength Index (GSI) for better understanding the rock mass behavior in further development of mine. All the three categories of rock mass, proposed by NAMNAM are considered for analyses. HOOK-BROWN and MOHR-COULOMB strength parameters, uniaxial compressive strength, overall strength and tensile strength of rock mass and failure envelope-range of different rock categories of MGM infer that the rock mass belongs to Category-I possesses good strength quality with deformation modulus of about 37583.7 MPa. Rock mass of Category-II is of fair quality with deformation modulus of 16693.6 MPa, whereas, the quality of Category-III is very poor and the deformation modulus is only about 1262.09 MPa. The rock mass uniaxial compressive strength of the MGM ranges from 23.35 to 0.236 MPa, whereas, the tensile strength ranges from 0.473 to 0.003 MPa depending on the rock categories. These strength parameters can be considered important in future development of the mine.

All the calculations are done for roadway tunnel situated at a depth of 271.5 m with RockLab. software developed by Rock Science Inc., Canada. Detail study of support requirements for the development of tunnels in MGM through different categories, especially, category-III & -II is advised.

Keywords: Maddhapara Granite Mine, GSI, deformation modulus, rock mass properties.

Introduction

In order to design, construct and mine the underground excavations safely and economically, it is important to know the rock mass properties thoroughly. The properties of rock mass differ considerably from that of intact rock. In the laboratory intact rock can be tested and the mechanical and strength properties can be known easily, but it is very difficult to know strength properties for rock mass as a whole using laboratory tests. However, it is possible to estimate strength properties of rock mass from laboratory tests of intact rock. Detail rock mass properties are equally important to develop methods and technologies leading to practically useful means for design of underground mine. The rock mass deformation modulus and strength are used as inputs to analyse the rock mass behavior by numerical models for any underground structures, like mine. The determination of the overall mechanical properties of a jointed rock mass is one of the most difficult works in rock
mechanics. It is generally an impossible task to develop a unique way that can be used in any practical purposes to predict the strength of the rock mass, since there are so many parameters that affect the deformability and strength of an arbitrary rock mass.

There are several traditional tests for analysis of deformation and strength parameters, but those can only be performed when the exploration audits are excavated and the cost of conducting in-situ tests is relatively high. Not many attempts have been made to develop methods to estimate the deformability and strength parameters indirectly. The Geological Strength Index (GSI), developed by Hoek et al. (1995), is one of them and used widely. GSI is largely based on experiences from a number of field observations (like block nature and size, behavior to drilling, rock recovery, etc.) of rock and its jointing natures (like number of joints, joints alteration, fillings in joints, nature of joint surfaces, etc.). Hence, GSI values can be estimated from the geological description of the rock mass. This is well fitted for rock mass characterisation without direct access to the rock mass from tunnels. Generally, the GSI system depends on the description of two factors like structure and block surface conditions of tunnel rock. The GSI system is the only system, although not adequate, that provides a set of mechanical properties without the efforts in field and laboratory. The properties that can be estimated from GSI include Hoek–Brown strength parameters $m$ and $s$ or the equivalent Mohr–Coulomb strength parameters $c$ and $\phi$ as well as elastic modulus $E_m$ for design purpose. Although it has been used widely in many countries, its applicability to the rock masses in Bangladesh has not been tested yet. Maddhapara Granite Mine (MGM) (Fig. 1) is the only underground hard rock mining venture in Bangladesh. GSI system can be used in Maddhapara mine to a better understanding of strength behavior of granite-granodioritic rock mass for its future development.

According to Namnam (2001), the rock mass of MGM has been categorised as Category-I (for slightly fissured rock), Category-II (for moderately fissured rock) and Category-III (for highly and very highly fissured rock). Rock mass belongs to Category-I is of very good to good quality with rough and unweathered joint surfaces. Rock mass of Category-II is characterised by slightly weathered joint surfaces, whereas, rock mass of Category-III is disturbed in nature with very poor quality, and the joint surfaces are slickensided and highly weathered.

Strength and deformation related parameters of rock mass of these categories were not considered for the development of MGM. Only intact rock strength was considered through laboratory tests for the development of the mine. It can be noted here that the intact rock strength from laboratory could not be treated as the strength of jointed rock mass.

In the present paper, an attempt has been made to estimate the deformation modulus and strength parameters of rock mass of Maddhapara Granite Mine with the direct information from GSI system.
Methodology

The parameters and/or information for quantifying the GSI values were obtained from block volume and joint condition factor as well as from site construction documents and field mapping data. GSI values for three categories (e.g. Category-I, II- and III) of rock mass were estimated from widely used and well-known classification chart developed by HOEK & BROWN (1997). HOEK & BROWN strength properties for intact rock, equivalent MOHR–COULOMB strength parameters and elastic modulus of the jointed rock mass were calculated using the resulting GSI values. The laboratory tests, like shear test, results of rock mass of the MGM were from different sources, e.g. NAMNAM (2000a & b and 2001), ISLAM (2002), etc.

RockLab, a software developed in 2002 by Rockscience Inc. of Canada has been used in order to estimate and calculate the rock mass parameters and strength properties defined by the HOEK & BROWN strength as well as MOHR–COULOMB strength criteria. Both the strength criteria significantly consider the GSI values.

The following procedures and tables have been considered for determining the strength and modulations of deformation of rock mass.
Estimation of Geological Strength Index- GSI

Several rock mass classification systems have been proposed and used in practice, such as the Rock Quality Designation-RQD (DEERE, 1968), Rock Mass Rating (RMR) of BIEINIAWSKI (1976), Q-system (BIEINIAWSKI 1976; BARTON et al. 1974 and BARTON 2002), GSI (HOEK et al. 1995 and HOEK et al. 1998) and RM3 system (Palmstrom 1996). A rock mass classification system can be used to estimate mechanical properties at a preliminary design stage. The GSI system seems to be the best choice for design because it can provide a complete suite of input parameters for numerical analysis of underground development. In a design process that employs numerical analysis, rock mass deformation modulus and strength are the only required input parameters. The GSI system developed by HOEK et al. (1997) is a chart suggesting definite numerical values and organised with the ‘blocks’ and respective ‘joints/fissures’ of the jointed rock mass. The value of GSI for the Maddhupara hard rock mass has been estimated from such chart as shown in Table 1.

Determination of Rock Mass Strength

The strength of a jointed rock mass depends on the strength of the intact rocks and the joint condition. MOHR-COULOMB criterion is expressed in terms of major ($\sigma_1$) and minor ($\sigma_3$) principal stresses as,

$$\sigma_1 = \frac{2c \cos \phi}{1 - \sin \phi} \cdot \frac{1 + \sin \phi}{1 - \sin \phi} \cdot \sigma_3$$  \hspace{1cm} (1)

and minor ($\sigma_3$) principal stresses as,

$$\sigma_1 = \sigma_3 + \sigma_{ci} \left( m_b \frac{\sigma_3}{\sigma_{ci}} + s \right)^2$$ \hspace{1cm} (2)

In rock mechanics, rock mass strength is generally represented by HOEK-BROWN strength equation as,

where, $m_b, s, a$ are constants for the rock mass and $\sigma_{ci}$ is uniaxial compressive strength of the intact rock.

Uniaxial compressive strength for the rock type of MGM is found from laboratory tests done by ISLAM (2002). The parameters $m_b, s, a$ can be found from

$$m_b = m_r \exp \left( \frac{GSI - 100}{28 - 14D} \right)$$ \hspace{1cm} (3)

$$s = \exp \left( \frac{GSI - 100}{9 - 3D} \right)$$ \hspace{1cm} (4)

$$a = 0.5 + \frac{1}{6} \left( e^{-GSI/15} - e^{-2013} \right)$$ \hspace{1cm} (5)
the following set of equations after HOEK et al. (2002) with the known values of GSI.

The value of $m_1$, HOEK-BROWN constant for granitic rock mass can be found from the published data and it is considered as 29 (HOEK & BROWN 1997). It is noted that the rock type of roadway tunnel of MGM is mainly of granitic to granodioritic. Here $D$ is a disturbance factor of rock mass due to blast damage and stress relaxation and can be found from the Table 2. The disturbance factor, $D$ is assumed to be zero for Category-I and -II, but for category-III it is 0.5.

\[
\sigma_c = \sigma_c' S^2
\]

\[
\sigma_c = -\sigma_c' m_2
\]

The uniaxial compressive strength of rock mass is obtained by setting $\sigma_3=0$ in equation 2, giving:
Table 2. Guideline for estimating disturbance factor, D (after Hoek et al. 2002).

<table>
<thead>
<tr>
<th>Description of rock mass</th>
<th>Suggested D value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent quality controlled blasting or excavation by Tunnel Boring Machine results in minimal disturbance to the confined rock mass surrounding a tunnel.</td>
<td>D=0</td>
</tr>
<tr>
<td>Mechanical or hand excavation in poor quality rock masses (no blasting) results in minimal disturbance to the surrounding rock mass.</td>
<td>D=0.5</td>
</tr>
<tr>
<td>Where squeezing problems result in significant floor heave, disturbance can be severe unless a temporary invert is placed.</td>
<td>No invert</td>
</tr>
<tr>
<td>Very poor quality blasting in a hard rock tunnel results in severe local damage, extending 2 or 3 m, in the surrounding rock mass.</td>
<td>D=0.8</td>
</tr>
<tr>
<td>Small scale blasting in civil engineering slopes results in modest rock mass damage, particularly if controlled blasting is used. However, stress relief results in some disturbance.</td>
<td>D=0.7</td>
</tr>
<tr>
<td>Very large open pit mine slopes suffer significant disturbance due to heavy production blasting and also due to stress relief from overburden removal.</td>
<td>Good blasting</td>
</tr>
<tr>
<td>In some softer rocks excavation can be carried out by ripping and dozing and the degree of damage to the slopes is less.</td>
<td>Poor blasting</td>
</tr>
<tr>
<td></td>
<td>Production blasting</td>
</tr>
<tr>
<td></td>
<td>D=1.0</td>
</tr>
<tr>
<td></td>
<td>Mechanical excavation</td>
</tr>
</tbody>
</table>

\[
\frac{\sigma_{3\text{max}}}{\sigma_{cm}} = 0.47 \left( \frac{\sigma_{cm}}{\gamma H} \right)^{-0.94}
\]

The tensile strength of rock mass (\(\sigma_t\)) can be found as,

\[
\sigma_t = \frac{\sigma_1 + \sigma_3}{2} - \frac{\sigma_1 - \sigma_3}{2} \left( \frac{d \sigma_1}{d \sigma_3} \right) \left( \frac{d \sigma_1}{d \sigma_3} \right) - \frac{1}{2} \left( \frac{d \sigma_1}{d \sigma_3} \right) + \frac{1}{2}
\]

\[
\tau = (\sigma_1 - \sigma_3) \sqrt{d \sigma_1 / d \sigma_3} / \left( d \sigma_1 / d \sigma_3 + 1 \right)
\]

\[
d \sigma_1 / d \sigma_3 = 1 + am_b (m_b \sigma_1 / \sigma_{ci} + s)^{a-1}
\]

the maximum confining stress, \(\sigma_{3\text{max}}\) for deep tunnels from the equation (6).

where, \(\sigma_{cm}\) is rock mass strength, \(\gamma\) is the unit weight of rock mass and \(H\) is overburden depth of the tunnel.
Normal ($\sigma$) and shear ($\tau$) strength are calculated according to BALMER (1952) as,

Where,

HOEK-BROWN strength parameters can be obtained from a series of laboratory tests, but in-situ triaxial tests are preferred. Beside the huge costs of such tests, it is often difficult to carry out large-scale triaxial tests to determine these parameters. For a practical solution, HOEK & BROWN (1980) showed that the properties controlling the rock mass deformability and strength were similar to the properties adopted in rock mass classification systems. Hence the rock mass classification could be used to estimate the constants $m$ and $s$. A chart for estimating such properties was proposed and widely accepted by the geotechnical community (HOEK & BROWN 1980). The GSI system consolidates various versions of the HOEK-BROWN criterion into a single simplified and generalised criterion that covers all of the rock types normally encountered in underground engineering. A GSI value is determined from the structure interlocking and joint surface conditions. GSI value ranges from 0 to 100.

\[
E_m \text{ (in GPa) } = \left( 1 - \frac{D}{2} \right) \sqrt{\frac{\sigma_{ci}}{100}} 10^{(\text{GSI}-10)/40} \quad \text{for } \sigma_{ci} \leq 100 \text{ MPa} \quad (9a)
\]

\[
E_m \text{ (in GPa) } = \left( 1 - \frac{D}{2} \right) 10^{(\text{GSI}-10)/40} \quad \text{for } \sigma_{ci} > 100 \text{ MPa} \quad (9b)
\]

The rock mass properties relating to the rock strength of the rock mass of MGM have been calculated and estimated from above mentioned equations and classification chart.

Calculation of Modulus of Deformation

According to HOEK et al. (2002), modulus of deformation relating to GSI is given by the following equations,

Results and Discussion

The three categories of rock mass of Maddhapara Granite Mine are studied for estimation of strength and deformation modulus. All the strength parameters and deformation modulus of intact rock and rock mass of Categories-I, -II and -III of MGM are calculated using RockLab and the results are given in Table 3.

The rock mass belongs to category-I shows uniaxial compressive strength ($\sigma_c$) of 23.354 MPa with tensile strength of 0.473 MPa (Fig. 2). The value of $\sigma_c$ for the rock mass of Category-III is 0.236 MPa and that of tensile strength ($\sigma_t$) is 0.003 MPa (Fig. 3). Again the values of modulus of deformation ($E_m$) for Category-I and -III are 37583.74 and 1262.09 MPa respectively. This implies that the rock mass of Category-I is more competent than Category-III in terms of strength. The Category-
Table 3. Strength and deformation parameters of rock mass of MGM.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Category-I</th>
<th>Category-II</th>
<th>Category-III</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{ci}$ (MPa)</td>
<td>105</td>
<td>70</td>
<td>40</td>
</tr>
<tr>
<td>GSI</td>
<td>73</td>
<td>62</td>
<td>27</td>
</tr>
<tr>
<td>$ml$</td>
<td>29</td>
<td>29</td>
<td>29</td>
</tr>
<tr>
<td>D</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Output**

Hoek-Brown Criterion

| mb         | 11.056 | 7.464 | 0.897 |
| s          | 0.0050 | 0.014 | 0.0006 |
| a          | 0.501  | 0.502 | 0.527 |

Failure Envelope Range for Tunnels

<table>
<thead>
<tr>
<th>$\sigma_{3max}$ (MPa)</th>
<th>3.728</th>
<th>3.588</th>
<th>3.227</th>
</tr>
</thead>
</table>

Mohr-Coulomb Fit

<table>
<thead>
<tr>
<th>C (MPa)</th>
<th>3.283</th>
<th>2.001</th>
<th>0.654</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi(^\circ)$</td>
<td>60.375</td>
<td>55.659</td>
<td>34.035</td>
</tr>
</tbody>
</table>

Rock Mass Parameters

| $\sigma_t$ (MPa) | -0.473 | -0.137 | -0.002 |
| $\sigma_c$ (MPa) | -0.473 | -0.137 | -0.002 |
| $\sigma_{cm}$ (MPa) | 23.353 | 8.389 | 0.236 |
| $\sigma_{cm}$ (MPa) | 49.365 | 26.047 | 4.457 |

Modulus of Deformation

$E_w$ (MPa)

|          | 37583.70 | 16693.60 | 1262.09 |

(Tunnel depth is 271.5 m and average unit weight for rock mass is 0.026 MN/m³)

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Rock Mass Strength and Normal-Shear stress plot for Category-I

![Rock Mass Strength and Normal-Shear stress plot for Category-I](image)

Fig. 2. Strength and normal vs. shear stress plot for rock mass of Category-I.
Fig. 3. Strength and normal vs. shear stress plot for rock mass of Category-III.

II shows (Fig. 4) a moderate strength properties ($\sigma_1=8.390$ MPa, $\sigma_2=0.138$ MPa and $E_1=16693.56$ MPa). The input values of intact Uniaxial compressive strength ($\sigma_u$) were 105, 70 & 40 MPa for Category-I, -II & -III respectively and those were laboratory tests results. But the actual situation differs considerably over the entire rock mass of any category. As for example, the uniaxial compressive strength of rock mass of Category-III found as 0.236 MPa, whereas the uniaxial compressive strength of intact rock is 40 MPa.

The input parameters of $m_i$ and $GSI$ were selected from a chart compiled by
HOEK & BROWN (1997) from a large number of case histories. They may differ for rock mass of MGM. Experienced designers and engineers might select more appropriate values of $m$ and GSI by considering the ranges defined for those parameters. In the present paper, for example, the value of $m$, was set for Category-III as 29, but in the actual classification chart of HOEK & BROWN (1997) it was assigned as 29±3. Hence, value of $m$, for the category-III of MGM rock mass ranges from 26 to 32. Similarly, GSI values may differ from one location to another within the same category of rock mass. The table for estimation of GSI is developed in such a way that a reasonable amount of range is quite advisable. The different strength parameters and deformation modulus found in this study can be used for a better as well as future development of mine tunnels.

Conclusions

With the estimation of GSI and $m$, the present study shows the rock mass of Category-I of the Maddhapara Granite Mine is more competent in terms of strength than Category-II and -III. HOEK-BROWN and MOHR-COULOMB strength parameters, uniaxial compressive strength, overall strength and tensile strength of rock mass and failure envelope range of different rock categories of MGM are calculated using the software, RockLab. These values signify that the rock mass belongs to Category-I possesses good strength quality with deformation modulus of about 37583.7 MPa. Rock mass of Category-II is of fair quality and the deformation modulus is 16693.6 MPa, whereas the quality of Category-III is very poor with a deformation modulus of about 1262.09 MPa. The uniaxial compressive strength of rock mass of the MGM ranges from 23.35 to 0.236 MPa whereas the tensile strength ranges from 0.473 to 0.003 MPa depending on the rock categories.

These strength parameters and deformation modulus for different categories may help designer to further development of the Maddhapara Granite Mine. This paper suggests for study of support requirements for the development of tunnels through different categories, especially Category-III &-II.

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ভূতাত্ত্বিক সামর্থ্য সূচক প্রয়োগে মধ্যপাড়া গ্রানাইট খনির শিলাসমষ্টির রূপবিকৃতি মানাঙ্ক ও সামর্থ্য উপাদান নির্ণয়

ইউনুস আহমদ খান

সারসংক্ষেপ

বাংলাদেশে মধ্যপাড়া গ্রানাইট খনি দেশের নির্মান শিল্পে বিশেষ অবদান রাখতে সক্ষম বলে আশা প্রকাশ করা হয়। মধ্যপাড়া গ্রানাইট খনির আরো উন্নয়নের সাবেক ভূতাত্ত্বিক সামর্থ্য সূচক প্রয়োগের মাধ্যমে খনির শিলাসমষ্টির রূপবিকৃতি মানাঙ্ক ও সামর্থ্য গুণাঙ্গণ পরিকল্পনা এবং মূল্যায়ন করা হয়েছে এই প্রসঙ্গে বিভিন্ন দৃষ্টিতে। শিলার অভ্যন্তরীণ ফটল, বিভিন্নসহ অন্যান্য সকল বিচ্ছিন্ন শিলার সামগ্রিক সময়কে বিশেষ মাত্রায় প্রভাবিত করে। শিলার সামগ্রিক সময়কের ভাবনায় উপর শিলার রূপবিকৃতি বহুলঃবেশি নির্ভরশীল। ‘নাম-নাম’ নামের উত্তর কোরিয়া একটি প্রতিষ্ঠান এই খনি উন্নয়নের সাথে সম্পর্কে। খুবমাত্র শিলার অভ্যন্তরীণ ফটলের উপর ভিত্তি করে নাম-নাম ২০০১ সালে খনির শিলা সমষ্টির প্রশিক্ষণ করে, যা প্রোসি-১ (স্বল্প ফটলমূলক শিলা), প্রোসি-২ (মাঝারী ফটলমূলক শিলা) এবং প্রোসি-৩ (গুরুত্ব ফটলমূলক শিলা) নামে আখ্যায়িত হয়। সামর্থ্য ও রূপবিকৃতি সম্পর্কে কোনো ধরনের উন্নয়ন নাম-নাম (২০০১)-এর প্রশিক্ষণে বিভিন্ন হয়নি। কেবলমাত্র পরীক্ষাগত আহ্রিত শিলার সামর্থ্য উপাদান বিবরণ করে এ ধরনের খনি উন্নয়ন বাঙালীর নয়, কারণে পরীক্ষাগত অন্ধতি আহরি উপাদান খনির শিলাসমষ্টির প্রতিনিধিত্ব করে না। উল্লেখ্য যে শিলাসমষ্টি হচ্ছে একক ধরনের বিযোগ শিলার বিভিন্ন সময় যে শিলায় শিলা এবং ফটল-বিভিন্নসহ অন্যান্য সকল বিচ্ছিন্ন একটি প্রাকৃতিক সমাবেশ অধীন করে। এই প্রক্রিয়াতে ভূতাত্ত্বিক সামর্থ সূচকের সাহায্যে খনির শিলা সমষ্টির সামর্থ গুণাঙ্গণ ও রূপবিকৃতি মানাঙ্ক 'হেক' ও অন্যান্য (২০০২) প্রতিষ্ঠান অন্তর্ভুক্ত করা হয়েছে। রক-ল্যাব নামের একটি কম্পিউটার সফটওয়্যারের সাহায্যে ফলাফল প্রক্রিয়া হয়েছে। এখানে খনির একটি যাতাতাত সূচককে বিবেচনায় আনা হয়েছে, যা ২৭.১৫ মি. নিচে অবস্থিত। সফটওয়্যারটিতে অন্তগামী হিসেবে শিলার অসীমবৃত্ত সর্বমান্য পীড়ন, ভূতাত্ত্বিক সামর্থ খুঁড়া, গ্রানাইট শিলার সামর্থ্য ডাক্ত এবং আন্দোলন ধ্রুব্বক ব্যবহার করা হয়েছে। বাস্তবায়নের হিসেবে 'হেক-ব্রাউন' সামর্থ্য সূচক, সূচকের সর্বাধিক অসীমবৃত্ত পীড়ন, দারনের সংস্থাস ও ধর্ম শক্ত, টান ও সামগ্রিক পীড়ন পাওয়া যায় এবং এসব উপাদানের মাধ্যমে খনির শিলাসমষ্টির রূপবিকৃতি মানাঙ্ক নির্ণয় করা হয়।

ফলাফল বিবেচনায় দেখা যায় যে, প্রোসি-১ হচ্ছে উচ্চ সামর্থ্য সম্পন্ন শিলাসমষ্টি যার রূপবিকৃতি মানাঙ্কের পরিমাণ ৩৭৫৮০.৭ মেগা-পাসকাল; প্রোসি-২ হচ্ছে মাঝারী সামর্থ্য সম্পন্ন শিলাসমষ্টি যার রূপবিকৃতি মানাঙ্কের পরিমাণ ১৬৬৯৩.৬ মেগা-পাসকাল এবং প্রোসি-৩ হচ্ছে নিম্ন সামর্থ্য সম্পন্ন শিলাসমষ্টি যার রূপবিকৃতি মানাঙ্কের পরিমাণ ১২৬২০.৯ মেগা-পাসকাল। বিভিন্ন শিলাপ্রোসি অনুসারে একক সামগ্রিক পীড়নের পরিমাণ ২৩.৩৫ থেকে ০.২৬৬ মেগা-পাসকাল পর্যন্ত এবং টান পীড়নের পরিমাণ ০.৪৭৩ থেকে ০.০০৩ মেগা-পাসকাল পর্যন্ত। প্রায় এসব ফলাফল খনির পরবর্তী উন্নয়ন কাজে বিশেষ ভূমিকা রাখতে পারে বলে আশা করা যায়।