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DEFORMATION MODULUS AND STRENGTH PARAMETERS OF SABALOKA IGNEOUS ROCK MASS

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ABSTRACT

Basalt and rhyolite rock masses are widespread through the north east part of Sabaloka plateau, 80 km north of Khartoum. The geological history of this area with the repeated changes in the volcanic activity, alternated with destructive events, caldera collapses, produced a very complex system. The variation in lithology, in the degree of tectonization and disturbance determined a wide spectrum of geotechnical materials, ranging from hard lavas to poorly welded pyroclastic deposits. Quarries, tunnels and other infrastructures were and will be constructed in these rock masses. This paper deals with determining the rock mass strength and deformability of these rocks in Sabaloka, in order to characterize them for the engineering purpose. The estimate of rock mass strength and deformability is reasonably well predicted through the use of empirical failure criteria such as the Hoek –Brown failure criterion which has gained broad acceptance in the rock mechanics community, and in situ test and empirical expressions to predict deformability. The rock mass properties and modulus of deformations of these rocks have been carefully assessed based on laboratory tests (uniaxial compressive, tensile test, triaxial test), and field investigations. The rock mass characterization approaches, Geological Strength Index (GSI) systems have been applied extensively to predict and evaluate the rock mass properties and support design. Numerical modeling studies (RocLab) based on field and laboratory data, have been used to evaluate the performance of these rock masses. Generally the main objective of the work reported in this paper was to increase knowledge of intact rock and defect properties of jointed basalt and rhyolite rock masses, develop reliable rock mass data and improve the ability to estimate the rock mass strength of these rocks.

تغطى كتل صخور البازلت والروليت الجزء الشمالى الشرقى من معقد هضبة السبلوقة النارى والتى تبعد حوالى 80 كلم شمال الخرطوم. ومن التاريخ الجيولوجى لهذه المنطقة ثبت انها قد تعرضت لنشاطات بركانية متعاقبة تسببت فى ظهور اشكال مختلفة من هذه الصخور تتراوح من الكتل النارية القوية الى رواسب صخرية عديمة الترابط او المكسرة. العديد من البنيات التحتية قد قامت فى هذه المنطقة مثل محاجر الخرسانة المكسورة والانفاق وغيرها من المنشئات الاخرى. وهذه الورقة تهتم بتحديد قوة تحمل هذه الكتل الصخرية وتحديد معامل تشوهها. ويمكن تحديد قوة هذه الكتل الصخرية بطريقة مقبولة باستخدام معيار او طريقة (هوك براون- Hoek Brown) والتى نالت رضا واسعا من قبل مجتمع ميكانيكا الصخور وتم استخدام العبارات التجريبية لاستنباط قيمة معامل التشوه لهذه الصخور. وتم استخدام التجارب الحقلية والمعملية بطريقة واسعة لتحديد القيم الفعلية لقوة كتل هذه الصخور ومعامل تشوهها. ومن هذه الاختبارات اختبار الضغط الاحادى المحور اختبار الشد واختبار الضغط ثلاثى المحاور باستخدام خلية هوك الى جانب التحريات الحقلية. ثم استخدم نظام مؤشر القوة الجيولوجى (GSI) لاستنباط الخصائص الهندسية لهذه الصخور. ثم الاستعانة ببرنامج Roclab الذى يعتمد على المعلومات الحقلية والمعملية المذكورة انفا لتقييم اداء هذه الكتل الصخرية. باختصار كان الهدف الاساسى من هذا البحث هو زيادة المعرفة بالصفات الجيوتقنية للصخور السليمة والصخور ذات الفواصل لمنطقة معقد السبلوقة النارى.

Keywords: Sabaloka, basaltic and rhyolite rock, GSI, deformation modulus, rock mass properties, characterization of Sabaloka rock masses, jointed rock masses

1. INTRODUCTION

In order to design a structure or underground excavations safely and economically, it’s important to know the rock mass properties thoroughly. The engineering 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 the 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 excavations. The rock mass deformation modulus and strength are used as inputs to analyze the rock mass behavior by numerical models for any underground structures. The determination of the overall mechanical properties of jointed rock mass is one of the most difficult tasks in rock mechanics. It is generally an almost impossible to achieve a 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 the rock mass. However there are several traditional tests for analysis of deformation and strength parameters, but those can only be performed when the exploration adits are excavated and the cost of conducting in situ tests is relatively high. A few 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. (1), which is widely used. GSI is largely based on experiences from a number of field observations (like geometry of intact blocks of rock), and it's jointing natures (like number of joints, joint alteration, filling in joints, nature of joint surface, etc.). The GSI values can be estimated from the geological description of the rock mass. Generally the GSI system depends on the description of two factors, structure and block surface conditions of the jointed rock. The properties for design purpose that can be estimated from GSI include Hoek – Brown strength parameters m_i and s or the equivalent Mohr-Coulomb strength parameters c and Φ as well as elastic modulus E_m. Although it has been used widely in many countries, it's applicability to the rock masses in Sudan has not been examined yet. GSI system can be used for Sabaloka basalt and rhyolite rock to estimate and evaluate the rocks mass properties and modulus of deformation for better understanding of strength behavior of this rock. According to the present study the rock mass of Sabaloka has been categorized as Category I (for slightly fractured rock), Category II (for moderately fractured rock) and Category III (for highly fractured rock). The location of the study area is shown in Figure 1. In this study, an attempt has been made to estimate the deformation modulus and strength parameters of rock mass of Sabaloka igneous rock with the direct information from GSI system.

2. METHODOLOGY

The information for quantifying the GSI values was obtained from block volume and joint condition factor as well as from site construction and field mapping data. GSI values of the three categories of rock mass were estimated from widely used and well known classification chart developed by Hoek and Brown (1997) Hoek and Brown strength properties for intact rock, equivalent Mohr- Coulomb strength parameters and deformation modulus of jointed rock mass were calculated using the resulting GSI values and the data from the triaxial laboratory tests conducted by the authors. RocLab, a software developed by Rock science Inc. of Canada (3) has been used in order to estimate and calculate the rock mass parameters and strength properties defined by the Hoek and Brown strength as well as Mohr-Coulomb strength criteria. The following procedures and tables have been considered for determining the strength and modulus of deformation of the rock mass.

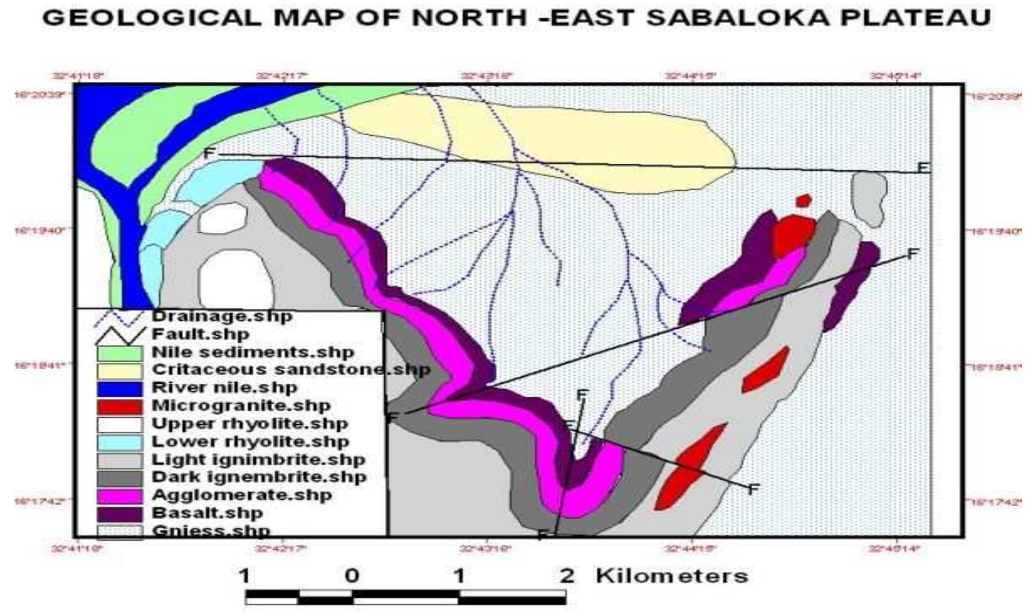
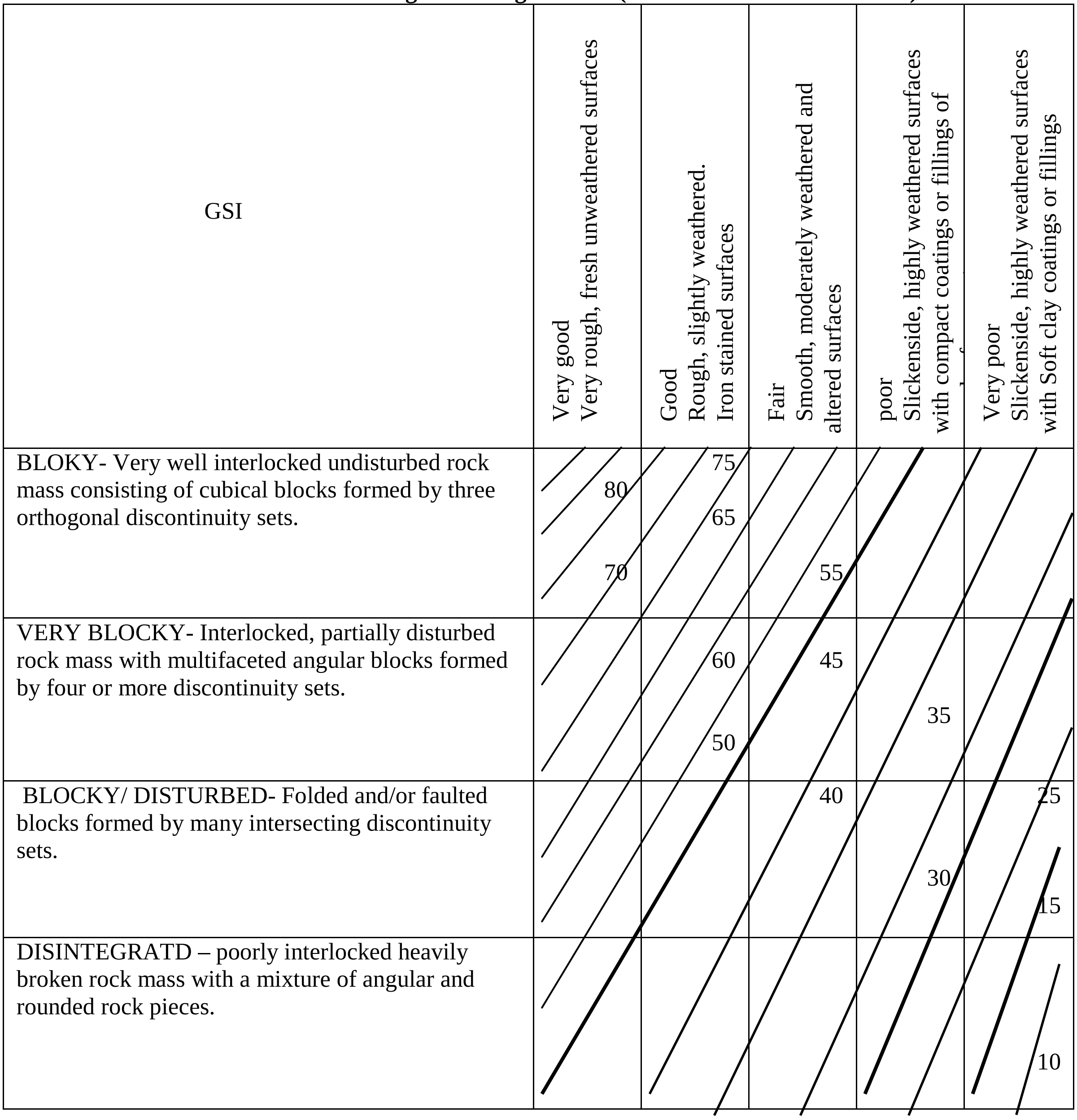


Fig. 1 Geological map of north east Sabaloka plateau

3. ESTIMATION OF GEOLOGICAL STRENGTH INDEX (GSI)

Several rock mass classification systems have been proposed and used in practice, such as the Rock Mass Rating (RMR) by Bieniawski (4), Q-system, Barton et al. (5), (GSI) Hoek et al. (6). 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 because it can provide a complete suite of input parameters for numerical analysis of underground excavation. 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 is given as a chart suggesting definite numerical values and organized with the blocks and respective joints condition of the jointed rock mass. The value of GSI for Sabaloka igneous rock mass has been estimated from this chart which is shown in Table 1.

Table 1 Chart for Geological Strength Index (after Hoek and Brown 1997)



GSI	Very good Very rough, fresh unweathered surfaces	Good Rough, slightly weathered. Iron stained surfaces	Fair Smooth, moderately weathered and altered surfaces	poor Slickenside, highly weathered surfaces with compact coatings or fillings of	Very poor Slickenside, highly weathered surfaces with Soft clay coatings or fillings
BLOKY- Very well interlocked undisturbed rock mass consisting of cubical blocks formed by three orthogonal discontinuity sets.					
VERY BLOCKY- Interlocked, partially disturbed rock mass with multifaceted angular blocks formed by four or more discontinuity sets.					
BLOCKY/ DISTURBED- Folded and/or faulted blocks formed by many intersecting discontinuity sets.					
DISINTEGRATD – poorly interlocked heavily broken rock mass with a mixture of angular and rounded rock pieces.					

4. DETERMINATION OF ROCK MASS STRENGTH

The strength of a jointed rock mass depends on the strength of the intact rock and the joint condition. The Mohr-Coulomb criterion is expressed in term of major stress (σ_1) and minor (σ_3) principal stresses as,

$$\sigma_1' = \frac{2c'\cos\phi'}{1-\sin\phi'} + \frac{1+\sin\phi'}{1-\sin\phi'}\,\sigma_3' \tag{1}$$

where c and Φ are the cohesive strength and angle of friction of rock mass respectively. However in rock mechanics, rock mass strength is generally represented by Hoek- Brown strength equation as:

$$\sigma_1' = \sigma_3' + \sigma_{ci}\left(m_b\frac{\sigma_3'}{\sigma_{ci}} + s\right)^a \tag{2}$$

where m_b, s, α, are constant for the rock mass and σ_{ci} is the uniaxial compressive strength of the intact rock. Uniaxial compressive strength for rock type of Sabaloka is found from laboratory tests done by the authors. The parameters m_b, s and α can be found from the following set of equations were given by Hoek et al. (7).

$$m_b = m_i \exp\left(\frac{GSI-100}{28-14D}\right) \tag{3}$$

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

$$a = \frac{1}{2} + \frac{1}{6}\left(e^{-GSI/15} - e^{-20/3}\right) \tag{5}$$

The value of m_i Hoek – Brown constant for basalt and rhyolite intact rock can be found from the determined triaxial tests data, and it has been found to be 14.5 for rhyolite and 12.5 for basaltic rocks. Here D is a disturbance factor of rock mass due to blast damage. The disturbance factor, D is assumed to be zero for all categories since there is no blasting damage.

5. CALCULATION OF MODULUS OF DEFORMATION

According to Hoek and Diederichs (8), modulus of deformation relating to the GSI is given by the following equations,

$$E_m\,(GPa) = \left(1-\frac{D}{2}\right)\sqrt{\frac{\sigma_{ci}}{100}}\,.\,10^{((GSI-10)/40)} \tag{6}$$

For $\sigma_{ci} \le 100$ MPa

$$E_m\,(GPa) = \left(1-\frac{D}{2}\right).\,10^{((GSI-10)/40)} \tag{7}$$

For $\sigma_{ci} > 100$ MPa

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

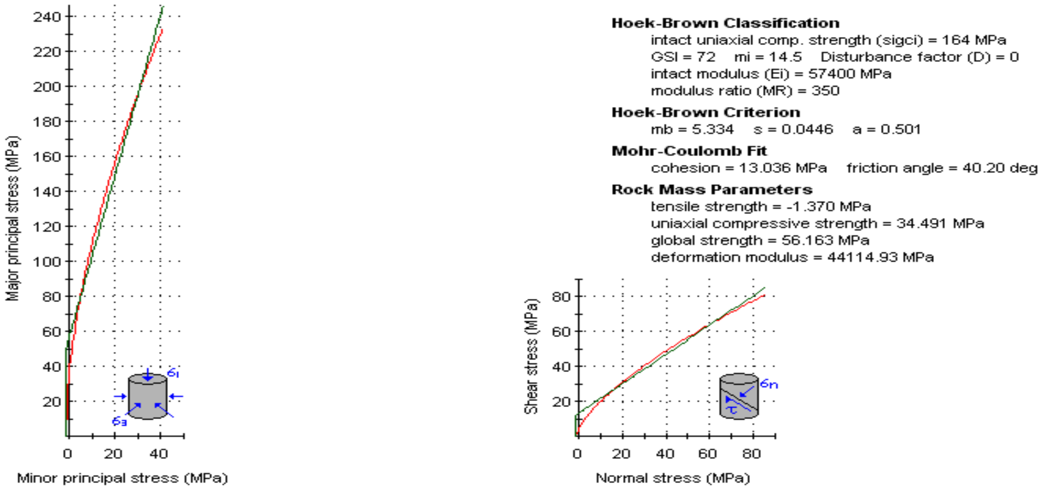
6. RESULTS AND DISCUSSION

The three categories of rock mass of Sabaloka are studied for estimation of their strength and deformation modulus. All strength parameters and deformation modulus of intact rock and rock mass of categories I, II and III of Sabaloka are determined using the RocLab program. The obtained results are given in Table 2. The rock mass belongs to category I, shows uniaxial compressive strength (σ_c) of 34.49 MPa with tensile strength of 1.37 MPa (Figure 2). The value of (σ_c) for the rock mass of category II is 4.3 MPa and that of the tensile strength is 0.121 MPa (Figure 3). The value of (σ_c) for category III is 0.826 MPa and 0.028 MPa for tensile strength.

Table 2 Strength and Deformation Parameters of rock mass of Sabaloka

Parameters	Category – I	Category – II	Category – III
Input σ_{ci} (MPa) GSI m_i D	 164 72 14.5 0	 96 45 12.5 0	 48 30 8.8 0
Output Hoek-Brown criterion m_b s α	 5.334 0.044 0.501	 1.753 0.0022 0.508	 0.722 0.0004 0.522
Failure envelope range for tunnels σ_3 max (MPa)	0.62	0.594	0.536
Mohr –Coulomb fit C (MPa) Φ (^{0})	 13.03 40.2	 4.737 31	 1.6 23.6
Rock mass parameters σ_t (MPa) σ_c (MPa) σ_{cm}(MPa)	 -1.37 34.49 56.163	 -0.121 4.303 16.72	 -0.028 0.826 4.927
Modulus of deformation E_m (MPa)	 44114.93	 7514.64	 585.96

(average unit weight for rock mass is 0.026 MN/m^3)



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Hoek-Brown Classification
        intact uniaxial comp. strength (sigci) = 164 MPa
        GSI = 72    mi = 14.5    Disturbance factor (D) = 0
        intact modulus (Ei) = 57400 MPa
        modulus ratio (MR) = 350
Hoek-Brown Criterion
        mb = 5.334    s = 0.0446    a = 0.501
Mohr-Coulomb Fit
        cohesion = 13.036 MPa    friction angle = 40.20 deg
Rock Mass Parameters
        tensile strength = -1.370 MPa
        uniaxial compressive strength = 34.491 MPa
        global strength = 56.163 MPa
        deformation modulus = 44114.93 MPa
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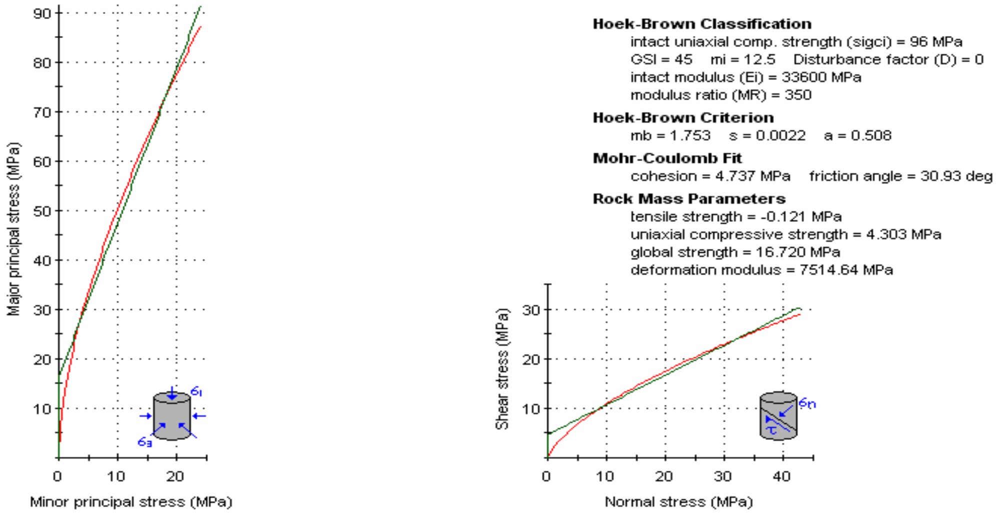
Fig. 2 Minor vs. major principle stress and normal vs. shear stress plot for rock mass of category-I



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Hoek-Brown Classification
        intact uniaxial comp. strength (sigci) = 96 MPa
        GSI = 45    mi = 12.5    Disturbance factor (D) = 0
        intact modulus (Ei) = 33600 MPa
        modulus ratio (MR) = 350
Hoek-Brown Criterion
        mb = 1.753    s = 0.0022    a = 0.508
Mohr-Coulomb Fit
        cohesion = 4.737 MPa    friction angle = 30.93 deg
Rock Mass Parameters
        tensile strength = -0.121 MPa
        uniaxial compressive strength = 4.303 MPa
        global strength = 16.720 MPa
        deformation modulus = 7514.64 MPa
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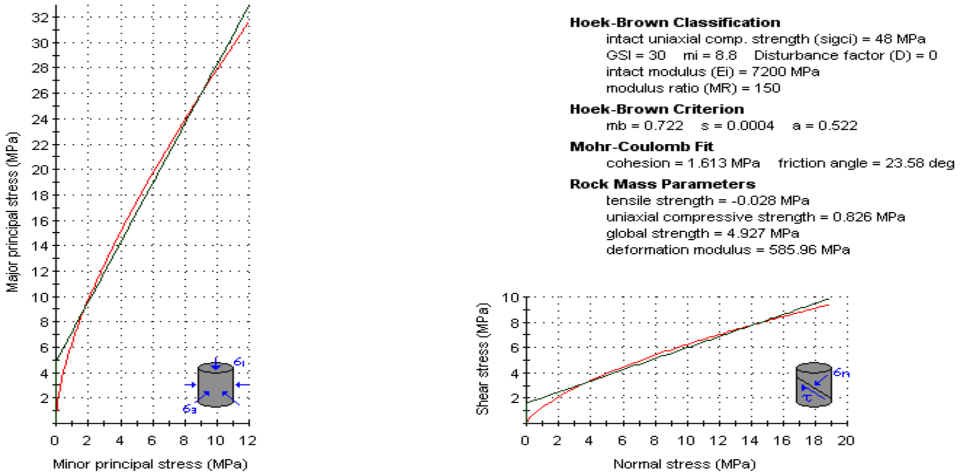
Fig. 3 Minor vs. major principle stress and normal vs. shear stress plot for rock mass of category – II



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Hoek-Brown Classification
        intact uniaxial comp. strength (sigci) = 48 MPa
        GSI = 30    mi = 8.8    Disturbance factor (D) = 0
        intact modulus (Ei) = 7200 MPa
        modulus ratio (MR) = 150
Hoek-Brown Criterion
        mb = 0.722    s = 0.0004    a = 0.522
Mohr-Coulomb Fit
        cohesion = 1.613 MPa    friction angle = 23.58 deg
Rock Mass Parameters
        tensile strength = -0.028 MPa
        uniaxial compressive strength = 0.826 MPa
        global strength = 4.927 MPa
        deformation modulus = 585.96 MPa
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Fig. 4 Minor vs. major principle stress and normal vs. shear stress plot for rock mass of category - III

The values of modulus of deformation (E_m) for category I, II and III are 44114 MPa, 7514 MPa and 586 MPa, respectively. This implies that rock mass of category I is more competent than category II and III in terms of strength. The input values of intact uniaxial compressive strength (σ_{ci}) from laboratory tests were 164, 96 and 48 MPa for category I, II and III respectively. But the actual situation is differs considerably for the rock mass of any one of these categories. For example, the uniaxial compressive strength of rock mass of category III was found to be 0.826 MPa, whereas the uniaxial compressive strength of intact rock is 48 MPa.

7. CONCLUSIONS

The present study shows that the rock mass of category I of Sabaloka basalt and rhyolite rock is more competent in terms of strength than categories 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 Sabaloka are determined using the software, RocLab. These values signify that the rock mass belongs to category I posses very good strength quality with deformation modulus of about 44115 MPa. Rock mass of category II is of good quality and the deformation modulus is 7514 MPa, whereas the quality of category III is poor with the deformation modulus of about 586 MPa. The compressive strength of rock mass of Sabaloka ranges from 34.49 to 0.826 MPa as the tensile strength ranges from 1.37 to 0.028 MPa depending on the rock categories.

The results of this article suggest for study of support requirements for the development of tunnels through different categories.

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