# The Necessity to Standardize Procedures of Providing Engineering Geological Data for Designing Road and Railway Tunneling Projects

Atefeh Saljooghi Khoshkar, Jafar Hassanpour



***Abstract*—**One of the main problems of design stage relating to many tunneling projects is the lack of an appropriate standard for the provision of engineering geological data in a predefined format. In particular, this is more reflected in highway and railroad tunnels projects in which there is a number of tunnels and different professional teams involved. In this regard, a comprehensive software needs to be designed using the accepted methods in order to help engineering geologists to prepare standard reports, which contain sufficient input data for the design stage. Regarding this necessity, an applied software has been designed using macro capabilities and Visual Basic programming language (VBA) through Microsoft Excel. In this software, all of the engineering geological input data, which are required for designing different parts of tunnels such as discontinuities properties, rock mass strength parameters, rock mass classification systems, boreability classification, the penetration rate and so forth can be calculated and reported in a standard format.

***Keywords*—**Engineering geology, rock mass classification, rock mechanic, tunnel.

## I. Introduction

ONE of the fundamental issues in designing tunnel projects that sometimes delays the tunnel design process is the lack of coordination between the engineering geology team and the design team. This prevents the design data required by the designers to be provided in a standard and suitable format. Owing to the fact that geological engineering teams provide tunnel design data with different methods and formats, designers can get frustrated. A case in point is the long-distance construction projects of the Tehran-North Freeway project. These projects encompass a large number of tunnels, each of which is studied by separate teams. Consequently, this can result in considerable differences in design.

Undoubtedly, there is a need to develop a comprehensive software solution for analyzing the raw data and calculating appropriate design parameters using standardized and accepted methods. Although a few software has been introduced for calculating engineering rock mass classification systems, namely RMI (rock mass index), or calculating the penetration rate of tunneling machines, none of these options is comprehensive enough. Some of these efforts are mentioned below.

One of the software that has been presented for classification of rock masses and selection of the tunnel support system is developed by Palmstrom in [1], [2] based on the RMI classification system in Excel environment. In this software, by inputting the block size, joint characteristics, and strength of intact rock, the uniaxial compressive strength of the rock mass is estimated. For instance, in many underground spaces, the estimation of the preliminary support can be provided only by importing the block size and the size of the tunnel, since it is more effective when only limited knowledge of the geological features is available. Later, when more information is available, more precise support will be estimated and designed. In a study that has been conducted in [2], tables and support charts are presented along with several examples. Indeed, an Excel spreadsheet has been presented from which the RMI (rock mass index) and the support parameters can be calculated easily. RMI is a system of evaluating rock support, similar to all others, and should be utilized in conjunction with a knowledge of the geology, as well as the ground conditions at the site [1], [2]. Additionally, in another publication by Palmström in [3] in 2009, he combined the three RMR (Rock Mass Rating), Q and RMI classification systems together and created a computer spreadsheet called RMR-Q-RMI for evaluation of the relationship between classifications. In fact, the main rock mass classification systems make use of similar rock mass parameters. As a result, the input parameters in all three systems could be combined into a set of common parameter tables. Subsequently, it enables the ground quality to be recognized directly in these systems from the characterization of only one set of observations. Hence, the estimated rock support identified in one system could easily be compared and checked with other systems efficiently [3].

Barton in [4] has presented a software for calculating the penetration rate of a tunneling machine, by which, with using QTBM, the performance parameters of the TBM, including the penetration rate and the forward speed of the machine are estimated [4].

Russo in [5] and [6], using the Excel spreadsheet, has proposed a method called “multiple graphs”. The tool is useful during the construction phase to identify the predefined support section type at the tunnel face and assess excavation behavior during rock tunneling.

In another research, Hassanpour et al. in [7]-[9] have presented an Excel spreadsheet for calculating the performance of tunneling machines based on their proposed model. Using

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this software, the penetration rate, advance rate of the machine, and time schedule for completing the tunnel can be predicted by inputting simple filed data (including intact rock strength and RQD (rock quality designation)). Hassanpour et al. in [10] have also designed an Excel spreadsheet for calculating the disc cutters life and their wear extent, using their proposed model. In addition, Hassanpour in [11] proposed an empirical prognosis model for evaluating cutter wear and life. Statistically, in a database, TBM performance, operational parameters and cutter wear changes and variations of geological parameters can be compiled and analyzed to acquire reasonable relationships between cutter life or wear and efficient geological parameters [11].

Zhang et al. in [12] suggested a comprehensive quantitative correlation combined with the intact rock properties to reflect the correlation of RMR and GSI (geological strength index) [12].

Somodi et al. in [13] highlighted relationships between GSI chart ratings and calculated GSI values based on RMR rock mass classification data and presented linear equations for estimating GSI from measured RMR89 values [13].

Recently, Hassanpour et al. in [14] presented geology-specific empirical relationships and investigated the relationships between different classifications including RMR, Q, and GSI in categorized engineering geological conditions [14].

In all of these efforts, they only considered a few parameters with diverse methods and format. In fact, they have not presented any comprehensive software for engineering geology tunnel studies in particular. In the present study, the chief aim is to design comprehensive software in order to facilitate the engineering geological studies of tunnels, which takes all the parameters required for the design of conventional and mechanized tunnels into account. These parameters include all the parameters required for designing the method of implementing the tunnel, the design of the primary support system, the final lining of the tunnel, and some specific parameters of the mechanized tunneling projects and some other essential parameters [15].

The objective of this study can be summarized as follows:

- To standardize the format of tunnels' engineering geological reports;
- To standardize the input data and output parameters of engineering geological studies;
- To facilitate the calculation of the rock mass engineering parameters, rock mass engineering classification, determination of the performance of tunnel boring machines, and other parameters;
- To minimize errors in all calculations;
- To present and apply up-to-date methods of estimating rock mass properties.

The main application of this research concerns the engineering geological studies of tunnels. Indeed, this software can be used by the consulting engineers as a useful tool in geological studies of tunnels, especially when a large number of tunnels are planned to be studied throughout a mountainous road or a railroad project.

## II. Research Methods

As cited in previous sections, the main purpose of this research is to figure out an appropriate solution to standardize the geological engineering studies' format in tunneling projects. To achieve this goal, initially, a survey was conducted on users who are a portion of the target community of this research and their essential requirements were evaluated. After recognizing the users' need, flowchart drawing and software planning were completed. In the next step, the study of software development methods led to the preference of the Visual Basic programming language (VBA) within the Excel environment. Consequently, it was decided to create a spreadsheet software with the most convenient user interface. In other words, VBA programming language enhances the ability of the developer to analyze data, design, report, and even to produce software [16]. In the final stage, in order to control the results and debug the software's bugs, a case study of engineering geology in the Sorkhdareh Tunnel Route related to the Tehran-North Freeway Project were performed using this software. One of the most notable purposes of this case study was to determine the engineering parameters of different units and evaluation of mechanical behavior of rock masses. Currently, the development of this software has been documented and it has been distributed for target users in tunneling projects in the country.

### *A. Basic Principles of Engineering Geology in Rock Tunnels*

Geological engineering studies in rock tunnels include an evaluation of the characteristics of rock mass indicating their behavior in the tunnel. These studies are prerequisites for studies on designing, controlling, elasticity, abrasion, and other stages. These studies should provide input data necessary for designing tunnels using the methods and techniques described below.

➢ Classification of rock Mass Engineering

One method of classification of rock mass engineering is RQD that was introduced by Deere in [17] as an index of assessing rock quality. It is the ratio of sum of sound pieces of core that are 100 mm (4 in.) or greater in length to the total drill run. There are either direct or indirect methods for calculating this parameter. In the direct procedure, the RQD is calculated by measuring the length of core pieces at a specific length of the core. Therefore, for determining the RQD in rock mass, it is essential to use coring procedure for drilling. Sometimes in the initial stages of the studies, cores are not available. Accordingly, some methods and relationships have been invented that by using them the approximation of RQD can be estimated indirectly [17]-[19]. Since the RQD completely depends on the spacing and the number of joints (discontinuities), existing methods often use this parameter to evaluate the RQD of rock mass. Moreover, the seismic survey method is another way to obtain an estimation of RQD using this parameter. Volumetric joint count is one of the most common methods for deterring RQD when there is no information of cores. In other words, RQD is estimated from the number of joints (discontinuities) per unit volume (Jv) based on (1) where Jv represents the total number of joints per cubic meter or the volumetric joint count and it is obtained according to (2) in [2]. RMR or the geomechanics classification was initially introduced by Bieniawski in [20]. Each type of rock mass should be represented by a separate geological structural unit within a given site in order to apply this classification.

Each structural unit is assigned six parameters (representing causative factors): 1. Uniaxial Compressive Strength (UCS) of intact rock material, 2. RQD, 3. Joint or discontinuity spacing, 4. Joint condition, 5. Groundwater condition, 6. Joint orientation. [20]. Rock mass Quality, Q-system is proposed by Barton in [21] for first time and more applications of it has been found later. There are six parameters (which represent causative factors) for every structural unit: 1. joint set number (Jn), 2. joint roughness number for critically oriented joint set (Jr), joint alteration number for critically oriented joint set (Ja), joint water reduction factor (Jw), Stress Reduction Factor (SRF), and volumetric joint count (Jv). Consequently, the final value of Q can be calculated based on (3) [21]. RSR was introduced in [22], [23] and GSI in [24]-[31].

$$RQD = 115 - 3.3Jv \tag{1}$$

$$Jv = \sum_{i=1}^{n} \frac{1}{S_i} \tag{2}$$

$$Q = \frac{RQD}{Jn} \frac{Jr}{Ja} \frac{Jw}{SRF} \tag{3}$$

➢ Rock Mass Strength Parameters

In addition to classification systems, some of the parameters that provide an estimation of rock mass strength relating to drilling are presented in [32], including in estimating the characteristics of rock mass mechanical excavation. Mostly, these parameters are composed of a feature of intact rock (usually UCS) and a parameter indicative of rock mass conditions.

➢ Estimation of Engineering Properties of Rock Masses Using Classification Systems

All those classification systems have been used to estimate some other parameters of the rock mass in addition to engineering classifications of it. Deformation modulus of the rock mass (Ed) has been estimated using RQD, Q, and other systems. A wider range of rock masses with RQD values ranging from 0 to 100% have been evaluated by Zhang and Einstein and they could introduce a correlation between RQD and modulus ratio according to (4). The deformation modulus of the rock mass (Ed) and the intact rock (Er) are represented in (4) [33]. Also, a mean value of modulus of deformation can be estimated by using Q system based on (5) [34]. Moreover, estimation of support pressure and support system can be evaluated using the approach of in [35]. To put it differently, Barton et al. [35] have graphed the support capacities of 200 underground openings in relation to the rock mass quality (Q). Through this analysis, they have discovered an empirical correlation for the ultimate support pressure, as indicated by (6) and (7). Where Pv is the ultimate roof support pressure in MPa, Ph is the ultimate wall support pressure in MPa, and Qw is the wall factor [35]. Reference [35] further suggested that when the number of joint sets is less than three, (6) and (7) are changed as (8) and (9), respectively. In order to estimate the support pressure in tunnels through poor rock masses (Q < 4), Bhasin and Grimstad suggested (10) where B is diameter or span of the tunnel in meters [36]. Furthermore, design of supports has been predicted using (11), (12-a), and (12-b). Depending on the size of the excavation and the height of the wall, bolt and anchor length are determined in terms of B or H in meters, respectively, as presented in [35]. The cohesive strength ($cp$) and angle of internal friction ($\varphi_p$) of the rock mass is derived using (13) and (14) proposed by Baron [34]. Barton introduced a method to estimate the in situ permeability (k) of the rock mass near the surface by evaluating the enhancement in Q through grouting, as described in (15) [37]. According to GSI classification system, generalized Hoek-Brown strength criterion for undisturbed rock masses are proposed by Hoek et al. [24] as shown in (16) and (17). Where $\sigma_1$ is maximum effective principal stress, $\sigma_3$ is minimum effective principal stress, $q_c$ is UCS, $m_b$ is reduced value of the material constant, and $m_r$ is Hoek-Brown rock material constant to be found from triaxial tests on rock cores. In (18) and (19), s and n are Hoek-Brown constants for the rock, and D is a disturbance factor.

$$\frac{Ed}{Er} = 10^{0.0186\,RQD - 1.91}, \text{ MPa.} \tag{4}$$

$$Ed = 10\left(\frac{Q \cdot qc}{100}\right)^{1/3}, \text{ GPa < Er {for Q = 0.1 to 100 and qc = 10 -200 MPa}.} \tag{5}$$

$$Pv = \left(\frac{0.2}{Jr}\right) Q^{-1/3} \tag{6}$$

$$Ph = \left(\frac{0.2}{Jr}\right) Qw^{-1/3} \tag{7}$$

$$Pv = \left(\frac{0.2 \cdot Jn^{1/2}}{3 \cdot Jr}\right) \cdot Q^{-1/3}, \text{ MPa.} \tag{8}$$

$$Ph = \left(\frac{0.2 \cdot Jn^{1/2}}{3 \cdot Jr}\right) \cdot Qw^{-1/3}, \text{ MPa.} \tag{9}$$

$$Pv = \left(\frac{40\,B}{Jr}\right) \cdot Q^{-1/3}, \text{ kPa.} \tag{10}$$

$$lb = 2 + \left(\frac{0.15\,B \text{ or } H}{ESR}\right), \text{ m.} \tag{11}$$

$$la = \left(\frac{0.40B}{ESR}\right), \text{ m, In Roof.} \tag{12-a}$$

$$la = 2 + \left(\frac{0.35\,H}{ESR}\right), \text{ m, In Walls.} \tag{12-b}$$

$$cp = \frac{RQD}{Jn} \times \frac{1}{SRF} \times \frac{qc}{100}, \text{ MPa.} \tag{13}$$

$$1.12.4\varphi_p = tan^{-1}\left(\frac{Jr}{Ja} \times Jw\right), \text{ Degrees.} \tag{14}$$

$k \approx \frac{1}{Q_c} = \frac{100}{Q \cdot q_c} \times \frac{1}{SRF} \times \frac{qc}{100}$, lugeons, (for Q = 0.01 to 100, H <

25 m, and 1 lugeons $= 1.0 \times 10^{-5}$, cm/sec). (15)

$$\sigma_1 = \sigma_3 + q_c\,[m_b \frac{\sigma_3}{q_c} + s]^n \qquad (16)$$

$$m_b = m_r \times \exp[\frac{GSI-100}{28-14D}] \qquad (17)$$

$$s = \exp[\frac{GSI-100}{9-3D}] \qquad (18)$$

$$n = \frac{1}{2} + \frac{1}{6}(e^{-GSI/15} - e^{-20/3}) \qquad (19)$$

## III. The General Structure of the Software

### *A. The Input Parameters of the Software*

Determining and specifying input parameters is crucial in geological engineering studies. According to Fig. 1, which indicates the flowchart of the input parameters of the software, the parameters that might be used for the next calculations are included as:

- General features of tunnel such as shape, length, width, height or diameter, and slope;
- The number and position of the engineering geological units;
- Intact rock properties: the results of fundamental field tests, including Schmidt hammer number (MPa), Is 50 (MPa), index manual test (MPa). In addition, the results of laboratory tests, including porosity, density, UCS (UCS, MPa), tensile strength;
- Discontinuities properties: number and type of joint sets, orientation, joint surface condition, including (weathering, roughness, aperture, filling, and wall strength), spacing, and persistence;

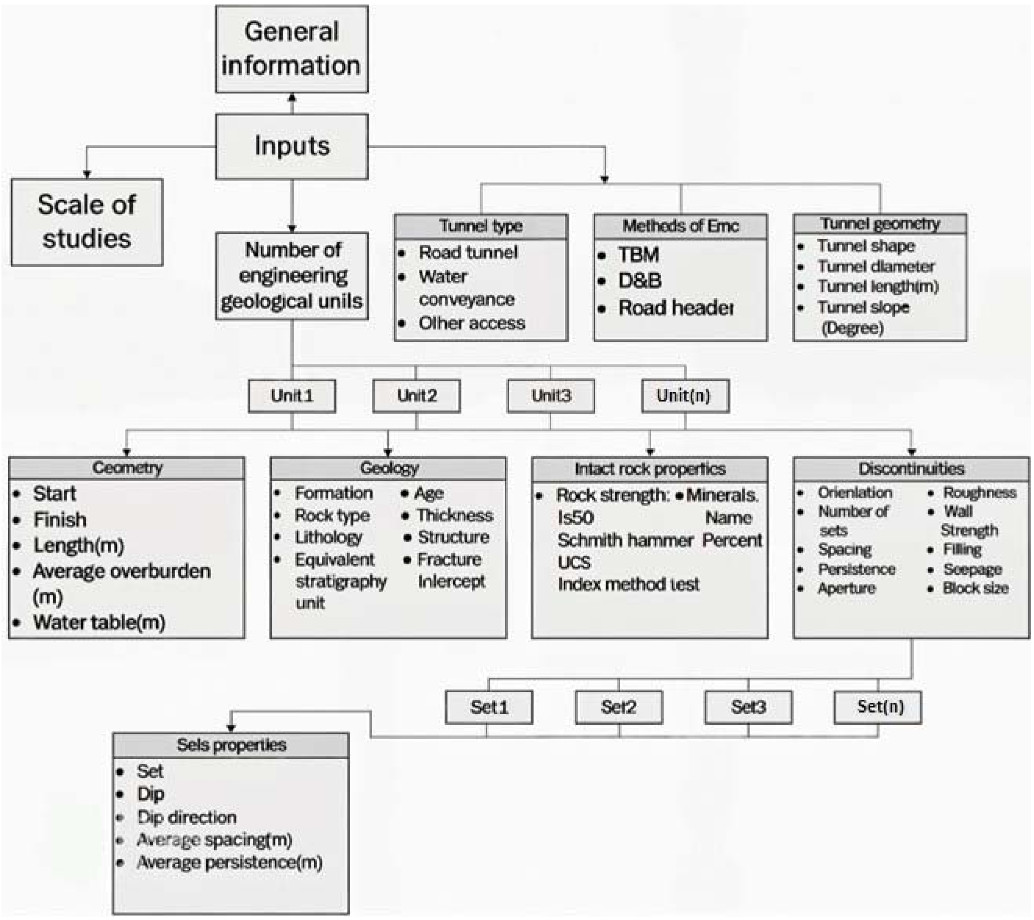



Fig. 1 Flowchart of software input parameters

### *B. The Output Parameters of the Software*

After importing the input parameters required by the user and running the program, a series of output parameters are calculated by the software and the user will be enabled to have access to them through a wide variety of menus. Furthermore, this software also has the ability to report the input, output parameters, and create these parameters in the form of tables in a standard format. According to Fig. 2, which indicates the flowchart of the output parameters of the software, the most important output parameters are calculated by the software in each geological engineering unit, and users will be able to use them in design phase including:

- The engineering parameters of rock mass such as the strength of rock mass (UCS), modulus of deformation of rock mass (Ed, GPa), in situ permeability of rock mass (K, cm/sec) in each engineering geological unit;

- Cohesion and angle of internal friction in each engineering geological unit;
- Stress conditions in different sections of the tunnel;
- The volume of groundwater inflow toward the tunnel in rock, including estimates of steady state flow and an initial flow of water in the face of the tunnel, based on empirical methods presented by Heuer in 1995, in each engineering geological unit [38];
- Results of engineering rock mass classification in each engineering geological unit;
- Prediction of squeezing conditions;
- Estimation of the support system in tunnels based on empirical models design of supports (Bolt length (lb.), Anchor length (la);
- Average stand-up time, the cohesion of rock mass (MPa);
- Prediction of Tunnel Boring Machine (TBM) performance in rock based on Hassanpour model and QTBM model.

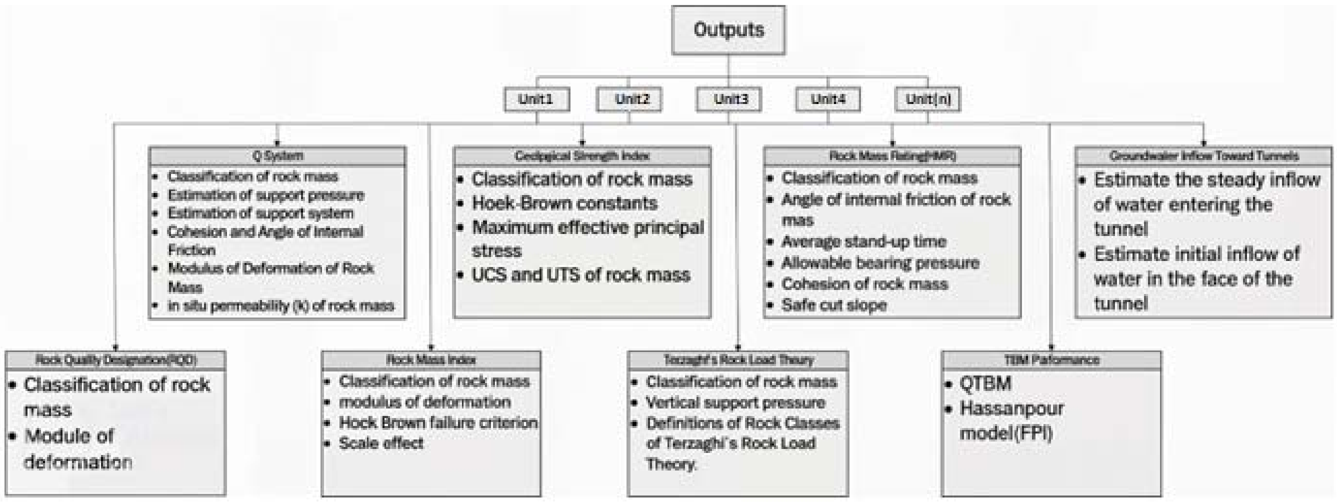



Fig. 2 Flowchart of software output parameters

## IV. A Case Study of Sorkhdareh Tunnel

In order to evaluate the validity of the software, one of the many tunnels that were being studied along Tehran-North Freeway route (Sorkhdareh Tunnel or Tunnel No. 4) was selected as the case study. According to engineering geological data collected as input data in field studies, the validity of output parameters of different parts of the software was evaluated. Engineering geological studies in this project have been carried out in order to determine the characteristics and engineering features of different units and to evaluate the mechanical behavior of tunnels. In fact, the main purpose of this study is to obtain information that can be used to predict the geotechnical conditions and the stability conditions of identified engineering geological units.

### *A. Tehran-North Freeway*

The Tehran-North Freeway project, which allows Tehran's access to the north of the country and the city of Chalus, is divided into four regions. Of these four regions, Zone 4 is in operation and Zones 1 and 2 are under construction. Zone 3 is also being studied. The second area that is under surveillance in this report is approximately 22 km long and starts from the place named Doab (which is the end of the first zone) and continues to the Zangulleh Bridge. Fig. 3 shows the route details in the second zone of the freeway. A large part of the studied area is located in the two Tertiary Territory and the Paleozoic - Southern Mesozoic, which is located between the two main drifts of the Alborz (Mesha in the south and Kandovan in the north), Fig. 4.

### *B. Engineering Geology*

➢ Identification of Engineering Geology Units

Using field observations, the physical and mechanical properties of different units have been examined and the results have been used to distinguish engineering geology units. Based on this, nine lithological units in the route of Sorkhdareh Tunnel are identified and separated from each other. This range includes Barout, Zagon, Mila Jeirud, Dorood, Ruteh, Nesen, Elika, Shemshak formations, and intrusive igneous masses. The general characteristics of engineering geological units in the Sorkhdareh Tunnel path are presented in Table I, Separation of Engineering Geological units within the route range of the Sorkhdareh Tunnel, and the sequence of these units is shown along the Sorkhdareh Tunnel path in Fig. 5.

➢ Geomechanical Features of Rocks Mass of Sorkhdareh Tunnel

In order to study the rocks mass characteristics, a number of geologic stations were selected in the field based on variations in rock mass characteristics, and the specific parameters surveyed and recorded in special worksheets. In this research, the engineering characteristics of the rock mass in each engineering geological unit are studied and the design data in these units are evaluated. The results of these studies are as follows:

1. Mechanical and Physical Parameters of Intact Rock

The physical, mechanical and strength properties of the rock exposures in the area are determined by performing preliminary field tests on surface outcrops. One of the simplest tests to determine the rock strength class is the manual index test, which is easily determined by the geological hammer and pocket knife in order to estimate the UCS of the rocks. In other words, the "strength of the rock mass," which is one of the output parameters, is related to the input parameters of UCS and tensile strength. The mean value of several methods, including UCS, point load test, Schmidt rebound hardness test, and index manual test, as shown in Fig. 6 and Table II, is applied to determine the strength of the rock mass.

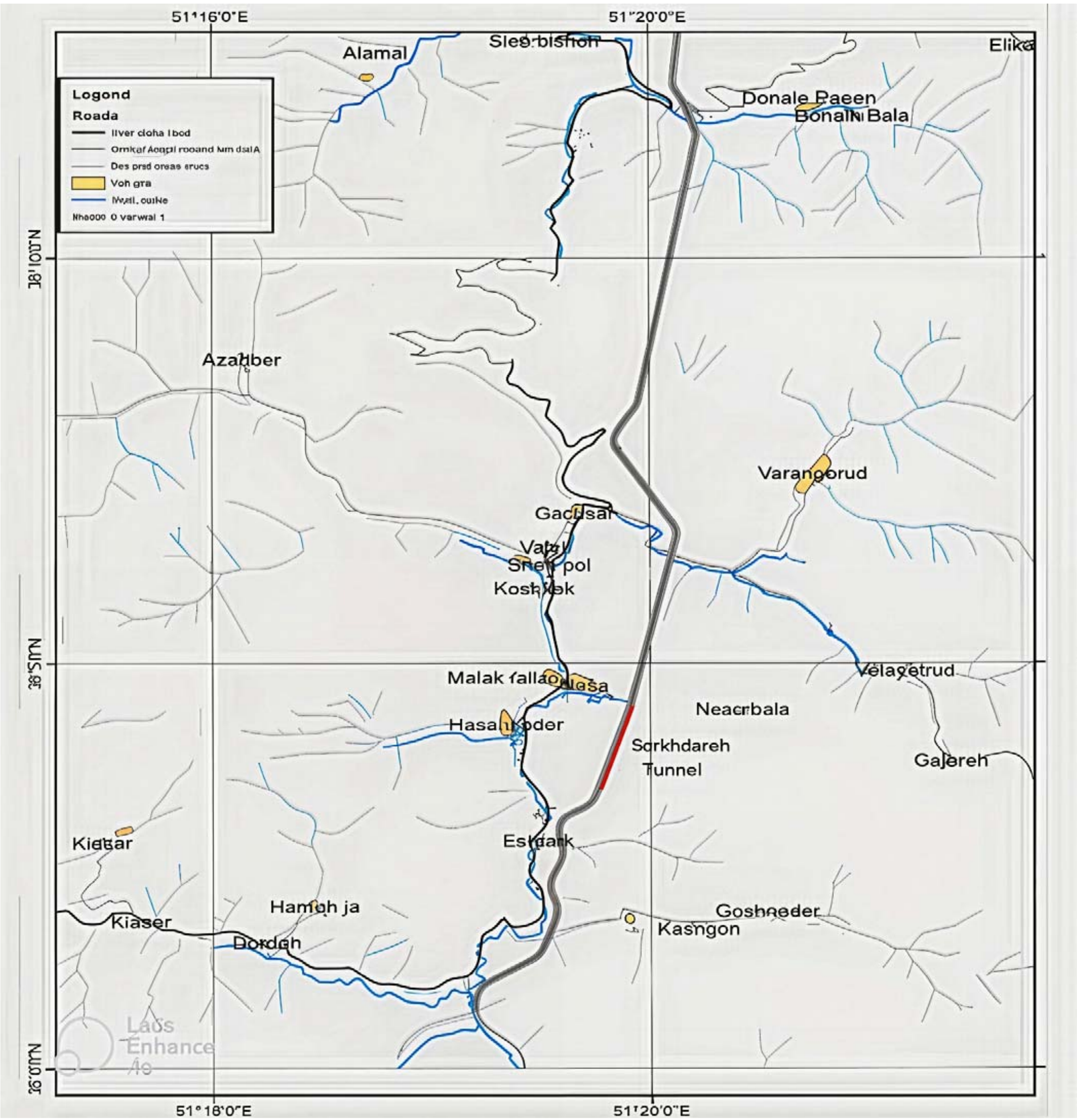



Fig. 3 The freeway path in the second zone and the Sorkhdareh Tunnel on the route

TABLE I
ENGINEERING GEOLOGICAL UNITS IDENTIFIED ON THE SORKHDAREH TUNNEL PATCH

| Units | Geology | | | | | | |
|---|---|---|---|---|---|---|---|
| | Formation | | Rock type | Lithology | Thickness (m) | Structure | Fracture Intercept (m) |
| | Name | Symbol | | | | | |
| Unit1 | Zagoun | Cz | RT-z | Thin bedded siltstone, sandstone with shale | 1.2 | Very blocky | F3- F4 |
| Unit2 | Laloon | Cl | RT-l | Thin to Thick bedded red Arcosic sandstone | 1.2-1.4 | Very blocky | F3- F4 |
| Unit3 | Top quartzite | Cq | RT-tq | Moderate to tick bedded quartzite | 1.2-1.3 | Blocky | F3 |
| Unit4 | Mila-Jeyroud | CDmj | RT-mj | Moderate bedded gray limestone | 1.2-1.4 | Laminated to very blocky | F3- F4 |
| Unit5 | Doroud | Pd | RT-d | Sandstone, Carbonate rocks, Quartzite with intercalations of intermediate to basic volcanic rocks | 1.2-1.3 | Blocky to very blocky | F2- F3 |
| Unit6 | Routeh | Pr | RT-r | Moderate bedded dolomitic limestone | 1.1 | Massive | F2 |
| Unit7 | Nesen | Pn | RT-n | Thick bedded limestone with chert | 1.2 | Blocky | F3 |
| Unit8 | Elika | Pn | RT-e | Moderate to thick bedded limestone | 1.3-1.4 | Very blocky | F4 |
| Unit9 | Shemshak | TRJs | RT-sh | Shale, sandstone, siltstone with intercalations of coal bearing shale | 1.2-1.5 | Laminated to very blocky | F3-F5 |

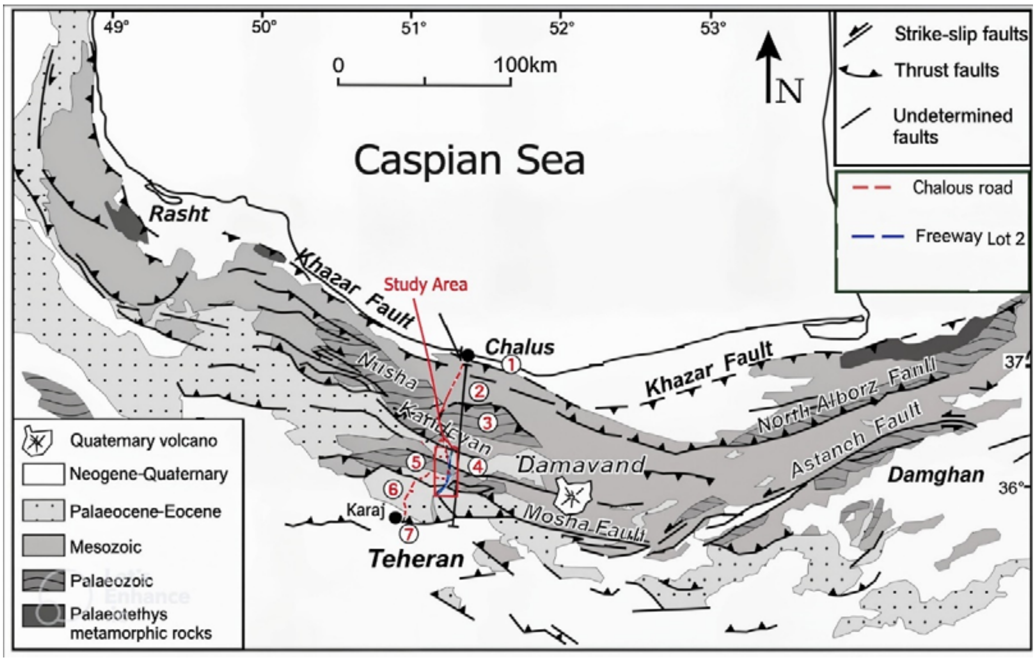


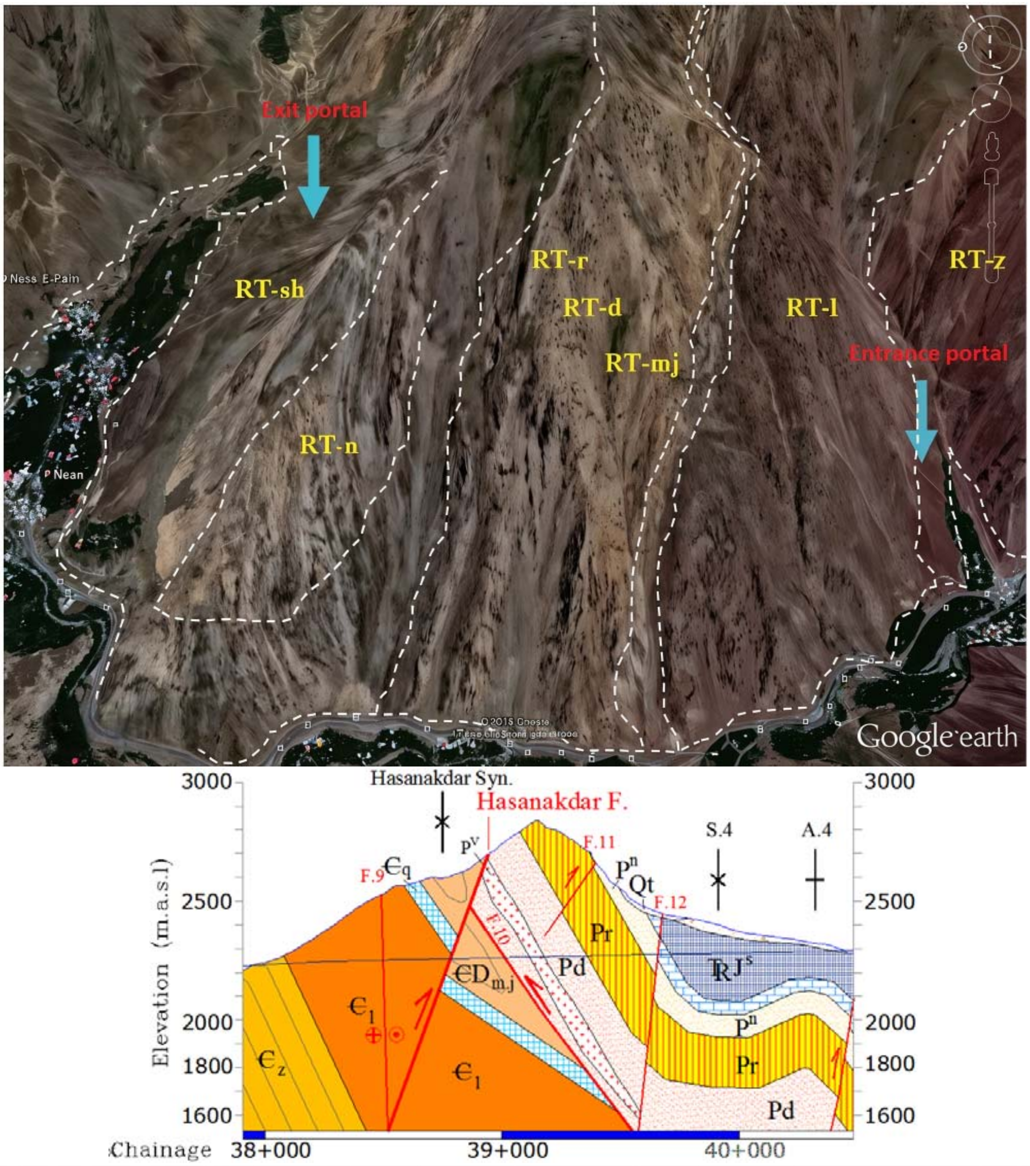

Fig. 4 Alborz structural stratigraphic division

TABLE II
PHYSICAL AND MECHANICAL PARAMETERS OF THE INTACT ROCK SORKHDAREH TUNNEL PATCH

| Units | Intact rock properties (Rock strength (MPa)) | | | | | | |
|---|---|---|---|---|---|---|---|
| | UCS | Is50 | Schmidt hammer | | Index manual test | Average | Selected value |
| | | | N | Strength | | | |
| Unit1 | 70 | 2.92 | 7.5 | 14.48 | 78 | 41.35 | 50 |
| Unit2 | 80 | 3.33 | 8.95 | 15.53 | 85 | 45.96 | 55 |
| Unit3 | 120 | 5 | 20 | 26.43 | 140 | 72.86 | 80 |
| Unit4 | 60 | 2.5 | 5.7 | 13.28 | 73 | 37.2 | 45 |
| Unit5 | 70 | 2.92 | 7.5 | 14.48 | 78 | 41.35 | 50 |
| Unit6 | 100 | 4.17 | 14.85 | 20.63 | 125 | 50.7 | 60 |
| Unit7 | 90 | 3.75 | 10.5 | 16.73 | 87 | 49.37 | 57 |
| Unit8 | 60 | 2.5 | 5.7 | 13.28 | 69 | 37.2 | 45 |
| Unit9 | 40 | 1.67 | 3.48 | 11.94 | 45 | 26.15 | 35 |

2. Properties of Discontinuities

The discontinuities that affect the geomechanical properties of rocks mass in the region are classified into three categories: 1) layering surfaces, 2) fractures and structural joints, and 3) minor faults. Mineral faults and joints are phenomena that are completely dependent on the tectonic and structural conditions of the region (in terms of orientation, spacing, number, etc.). Layering surfaces are also phenomena whose properties depend on the sedimentation and tectonic conditions of the area. On the other hand, the characteristics of discontinuities that affect the geomechanical behavior of rock mass can be classified into two groups of geological characteristics and mechanical properties. The features of the first category include the spatial and geometric location of the discontinuities (slope orientation, slope angle, number of joint sets, spacing, and persistence). In fact, all these parameters have been studied according to the information from the surface outcrops of the rock mass of the Sorkhdareh Tunnel patch. In this project, in order to determine the characteristics of the region's discontinuities, the whole patch is divided into several structural and geological engineering areas. Particularly, in each region, a number of distinct stations attempted to distinguish discontinuity features. The summary of the results of these studies is presented in Table III, and the page of discontinuities features of the software is shown in Fig. 7.




| Straligraphio Unit | $\epsilon_z$ | $\epsilon_1$ | Cz | Pd $P^V$ | Pd | Pr | Cz | TRJ$^s$ |
|---|---|---|---|---|---|---|---|---|
| Lithology | Sandciane sno Shnalone | Sandstone | Crushed rocks | Sondulens & Dvdlioouta vilh tuh Valnmom R | | Dolonailc fime | Cnntiied Iurin | Shale and Sandstone |
| Layer Thickness | Thin | Thick | Thin | Moderate | | | Thin | Thin |
| Engineering Ceological Type* | RT-z | RT-1 | EZ-s | ET-d | | ET-r | EE-10 | ET-sh |
| Number of Joint Sats | B+2ln+H | E+2ls+R | CR | B+2ls+R | | B+2ls+R | CR | B+3ls+R |
| Jolnt Volome (Jv) | 13-16 | 7.5-13 | >23 | 10-20 | | 4.5-10 | >22 | >13 |
| Av. Discontinuilies Cond | Good | | V Poor | Cood to Falr | | Cood | VPoor | Tuir to Poor |
| U.C.S. (MPA) | 70 | 80 | <50 | 60 110 | 65 | 100 | <50 | <70 |
| RQD (%) | 60-70 | 70-90 | <40 | 50-80 | | 50-100 | <40 | 40-65 |
| Elastic Modnlus (CPa) | | 9 | 3-10 | 8-20 | | 35 | 3-10 | 2-9 |
| Abrnslvity (Table2) | 1000-1300 | 100-500 | 1000-1500 | 1000-1500 | | 1500-2500 | >2500 | >2500 |
| Denslty (ton/m$^3$) | 2.3-2.5 | | <2.5 | 2.3-2.5 | | 2.5-2.7 | <2.5 | 1.8-2.4 |
| Groundwater Condition (Table 6) — INITUN o/mlo) | 1-3 | 1-3 | 5-10 | 2-4 | | 20-80 | 10-15 | 5-1U |
| Groundwater Condition (Table 6) — DEICRIPTION | DAMP | | | | | WIT oo INIDTUT | WET | DAMP |
| EMR (adjusted) | 45-50 | 50-55 | 20-30 | 45-63 | | 65-70 | 20-36 | 26-51 |
| Basle EMR | 50-55 | 55-60 | 20-40 | 50-68 | | 70-75 | 25-40 | 31-56 |
| GSI Value ( Table 1) | 40-50 | 45-55 | 20-40 | 65-75 | | 65-75 | 20-50 | 30-50 |
| Q Value | .6-1.2 | .7-1.4 | <.01 | .5-2 | | 2.2-4.5 | <.01 | .05-.9 |
| Boreabllity olass (Table 8) | B-II to B-4 | B-II bo B-III | B-IV to B-V | B-II to B-III | | B-II | B-b B-4 | B-IV |

Fig. 5 Engineering Geological units identified along with the Sorkhdareh Tunnel

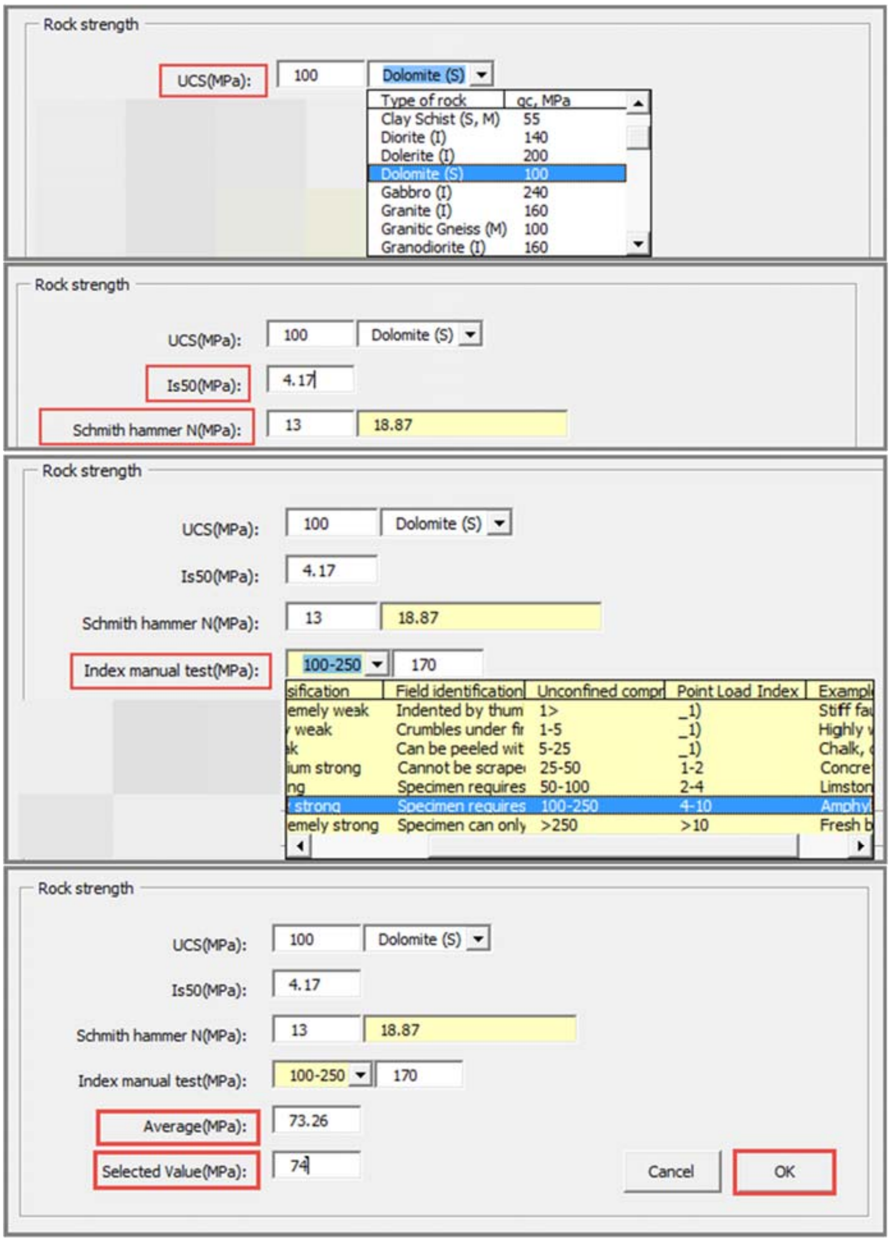



Fig. 6 UCS, point load test, Schmith Number, and final calculation of intact rock strength with the average of the four previous methods and selecting the appropriate number

➢ Classification of Rock Mass Engineering

1. RQD Classification

In order to determine the RQD of the rocks mass of the region, firstly, the average spacing between the discontinuities is determined by statistical studies in each unit of geological engineering. Then, using the Palmstrom model, the RQD of the rock mass has been presented in Table IV.

2. Geomechanical Classification RMR

The rock mass of the tunnel is classified according to the geological conditions of the site. Indeed, the rock mass of the tunnel is divided into different regions and each region is classified individually. For this purpose, firstly, using the straight-line observations of the tunnel path in each range, parameters such as the average of the RQD, joint conditions, and spacing of discontinuities were determined. Consequently, the RMR value for different ranges was determined. The classification results of rocks mass involving the Sorkhdareh Tunnel patch in different sections based on the RMR system are presented in Tables V and, and the page of rock mass geomechanical classification of the software is shown in Fig. 8.

3. Classification System Q

The rocks mass of the Sorkhdareh Tunnel patch is investigated based on the classification of the Q system in different sections, and the results are presented in Table VII. According to Q values and empirical relationships, some required functional parameters have been calculated and are presented in Table VIII. The flowchart of Q classification and its applications are shown in Fig. 9. In addition, the page of rock mass quality Q system classification of the software is shown in Fig. 10.

TABLE III
RESULTS OF DETERMINATION OF DISCONTINUITY CHARACTERISTICS IN DIFFERENT GEOLOGICAL ENGINEERING UNI

| Discontinuities | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Units | Spacing | | | | Orientation | | | | | | Block size | | | Persistence of critical joint(m) | |
| | Number of joint sets (J) | Joint spacing(m) | | | Coordinate | | Bedding | Mean joint set orientation | | | Block Size Index Ib ($m^3$) | Volumetric Joint Count Jv (Joints/$m^3$) | | | |
| | | 1 | 2 | 3 | x | y | | J1 | J2 | J3 | | Jv | Jv Description | Persistence | Description |
| unit1 | 3 | 0.1-0.3 | 0.2-0.4 | 0.5-1 | 528830 | 3989874 | 350/70 | 054/50 | 320/45 | 235/60 | 0.42 | 9.66 | Medium-sized blocks | 5-Mar | Medium persistence |
| unit2 | 3 | 0.2-0.5 | 0.3-0.6 | 0.4-1 | 528103 | 3990346 | 172/85 | 145/87 | 220/70 | 260/20 | 0.5 | 6.51 | Medium-sized blocks | 3-Jan | Low persistence |
| unit3 | 3 | 0.4-0.8 | 0.5-0.9 | 0.3-0.6 | 545272 | 3994590 | 200/69 | 020/31 | 120/65 | 300/84 | 0.58 | 5.32 | Medium-sized blocks | 5-Mar | Medium persistence |
| unit4 | 3 | 0.1-0.4 | 0.1-0.8 | 0.1-0.8 | 545318 | 3994564 | 120/84 | 300/62 | 200/40 | 160/16 | 0.38 | 8.44 | Medium-sized blocks | 5-Mar | Medium persistence |
| unit5 | 3 | 0.3-0.6 | 0.2-0.6 | 0.2-1 | 546162 | 3994575 | 200/80 | 240/65 | 160/45 | 040/10 | 0.48 | 6.39 | Medium-sized blocks | 5-Jan | Medium persistence |
| unit6 | 3 | 0.8-1.5 | 0.5-0.9 | 0.8-1.5 | 528636 | 3991322 | 350/85 | 310/60 | 070/55 | 080/15 | 0.99 | 3.17 | Medium-sized blocks | 3-Jan | Low persistence |
| unit7 | 3 | 0.2-0.8 | 0.2-0.6 | 0.5-1.5 | 528080 | 3992152 | 075/65 | 200/90 | 5/5/2010 | 290/75 | 0.63 | 6.6 | Medium-sized blocks | 3-Jan | Low persistence |
| unit8 | 3 | 0.6-0.9 | 0.8-1 | 0.5-1 | 529739 | 3992554 | - | 080/70 | 327/60 | 160/20 | 0.8 | 3.77 | Medium-sized blocks | 3-Jan | Low persistence |
| unit9 | 3 | < 0.1 | < 0.1 | < 0.1 | 529688 | 3992254 | - | 330/75 | 255/70 | 120/25 | 0.09 | 30 | Very small blocks | 10-May | Medium persistence |

TABLE IV
RQD CLASSIFICATION AND ESTIMATION OF ROCK MASS DEFORMABILITY MODULUS

| Units | RQD | | | |
|---|---|---|---|---|
| | RQD | | Application of RQD | |
| | | | Deformation modulus of the rock mass (MPa) | |
| | RQD(%) | Quality Description | Er | Ed |
| Unit1 | 83 | Good | 0.88 | 74.44 |
| unit2 | 94 | Excellent | 1.1 | 105.46 |
| unit3 | 97 | Excellent | 1.2 | 120.13 |
| unit4 | 87 | Good | 0.92 | 81.78 |
| unit5 | 94 | Excellent | 1.04 | 100.03 |
| unit6 | 100 | Excellent | 0.98 | 105.02 |
| unit7 | 97 | Excellent | 0.91 | 90.08 |
| unit8 | 100 | Excellent | 0.89 | 93.36 |
| unit9 | 16 | Very poor | 0.7 | 9.78 |

4. GSI Classification System

The rocks mass of the Sorkhdareh Tunnel patch is also evaluated based on the GSI classification system. Regarding surface surveys, the relationships between RMR and GSI and the engineering judgment of the values of this parameter were obtained for each of the tunnel route units separately. The results obtained for this classification system are presented in Tables IX and X. The flowchart of GSI classification and its applications are shown in Fig. 11. In addition, the page of GSI classification of the software is shown in Fig. 12.

## V. CONCLUSION

In the present study, the main goal has been to design a comprehensive software using macro capabilities and Visual Basic programming language through Microsoft Excel to facilitate geological engineering studies of tunnels in which all the parameters required for the design of traditional and mechanized tunnels are included. These parameters contain all the required parameters for designing the tunnel implementation, the design of the temporary durability system and the final tunnel wear. In fact, in the design of this software, it has been tried to provide the convenience of entering data for users. Furthermore, the outputs are directly available to the designers in order to apply for tunneling projects. It is suggested that the geological engineering teams provide the design data required by the designers using the software presented in this research and obtain geological engineering reports with high accuracy and speed in the standard format.

For evaluating the validity of the software, Sorkhdareh Tunnel was chosen as the case study. Based on engineering geological data collected as input data in field studies, the validity of output parameters of different parts of the software was evaluated. Engineering geological studies in this project have been conducted to determine engineering features of different units and to evaluate the mechanical behavior of tunnels.

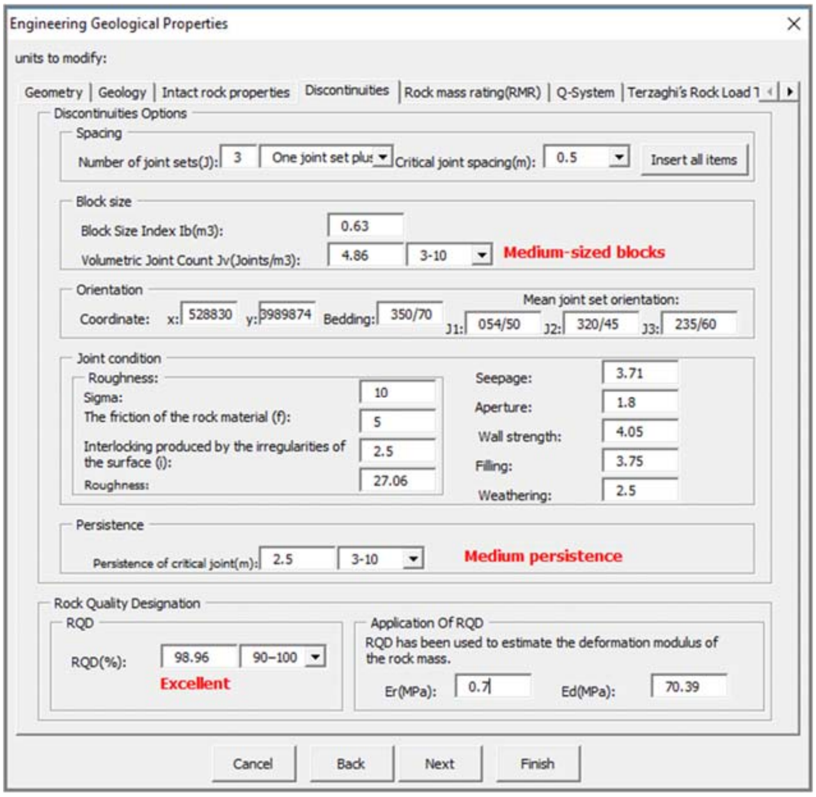



Fig. 7 The features of discontinuities relating to each unit of engineering geology

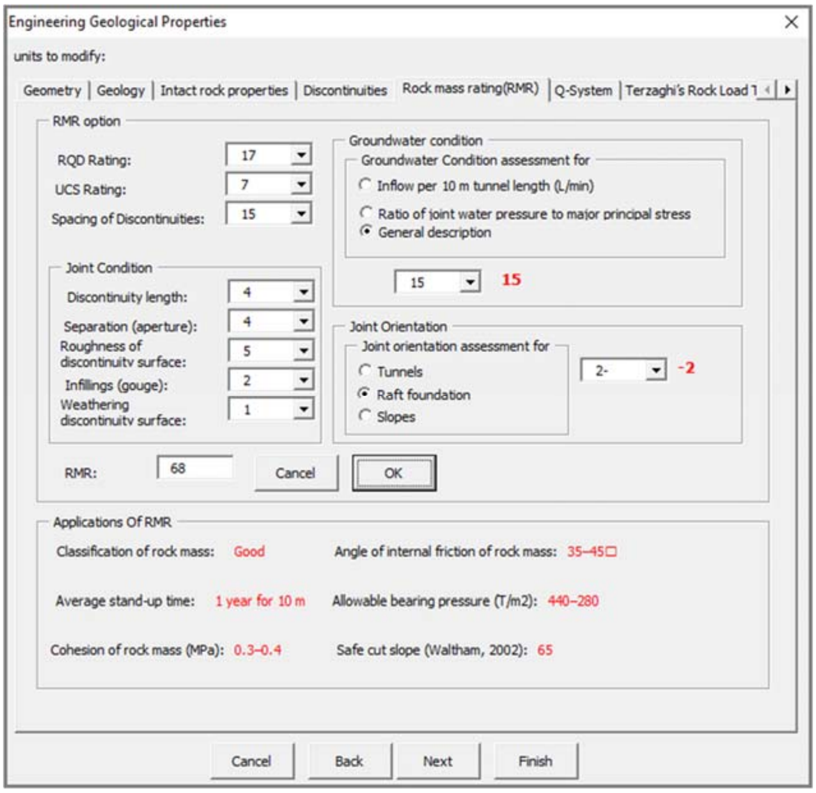



Fig. 8 Rock mass geomechanical classification (RMR), and applied parameters calculated based on RMR value

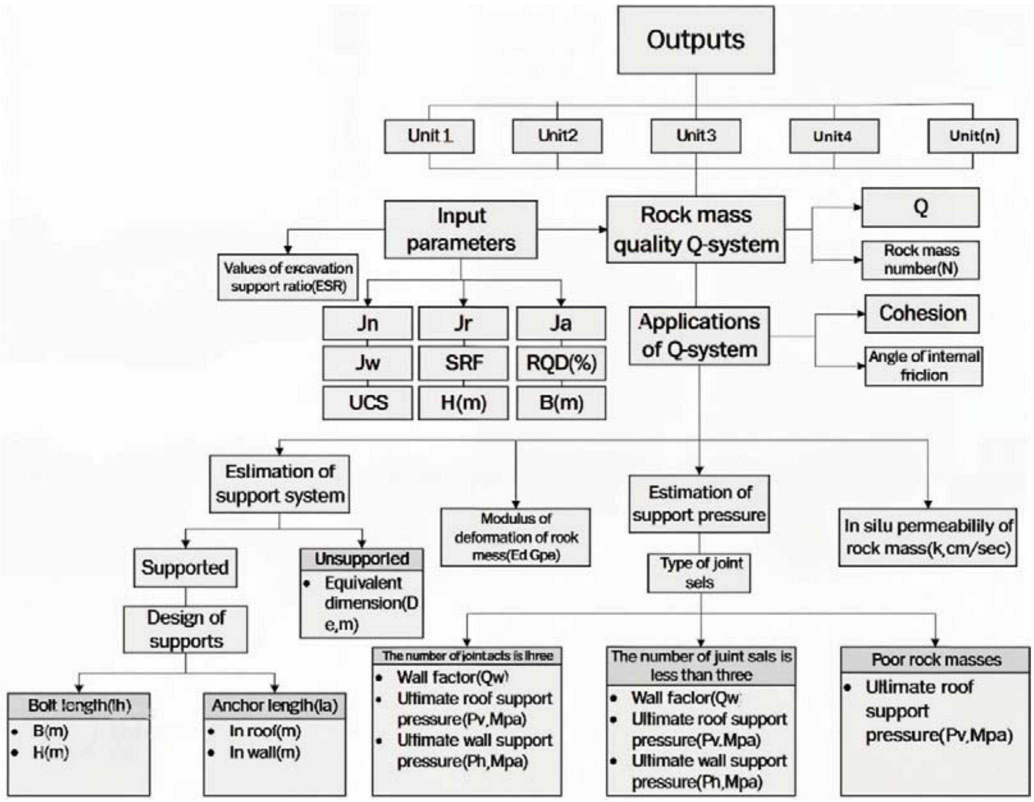



Fig. 9 Flowchart of rock mass quality-Q system classification, and applied parameters calculated based on Q value

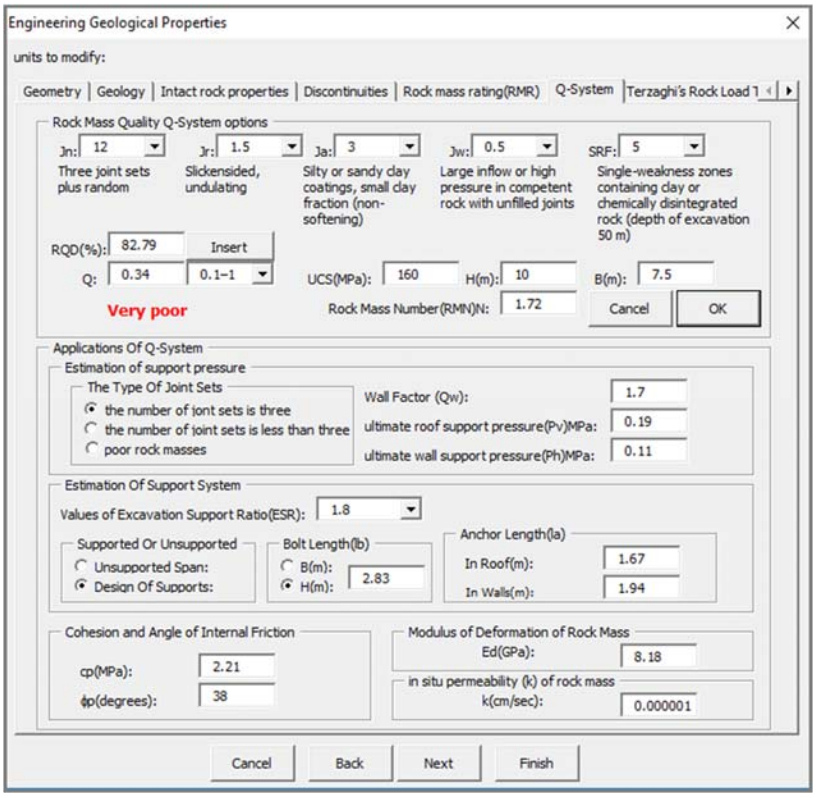



Fig. 10 Rock mass quality-Q system classification, and applied parameters calculated based on Q value

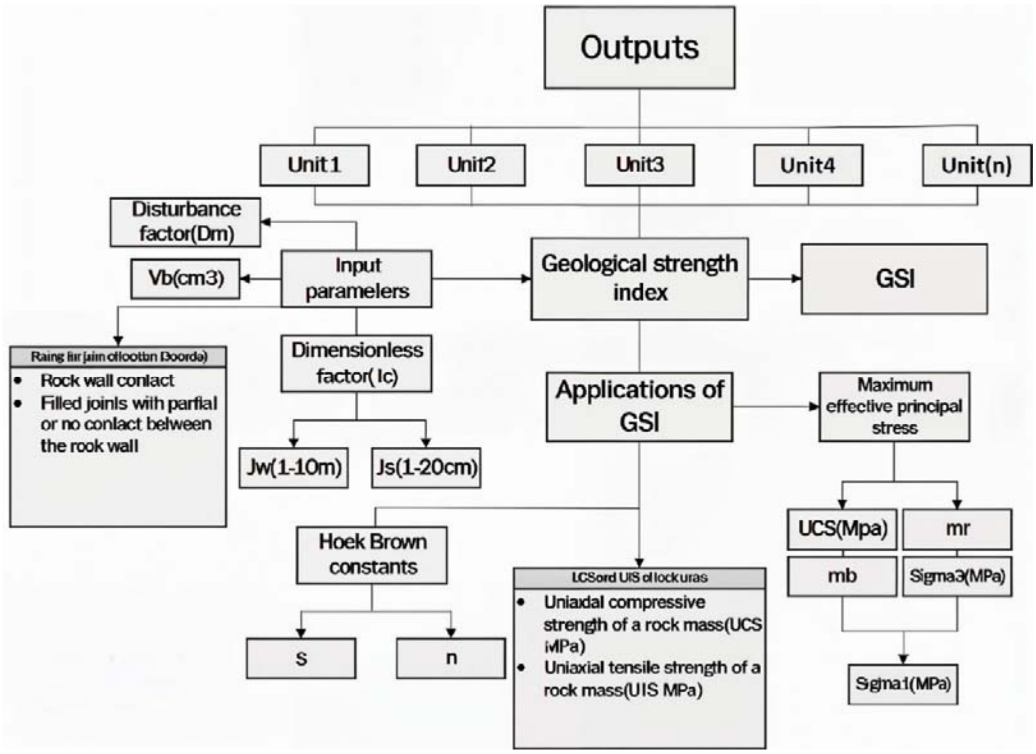



Fig. 11 Flowchart of GSI classification (GSI), and applied parameters calculated based on GSI value

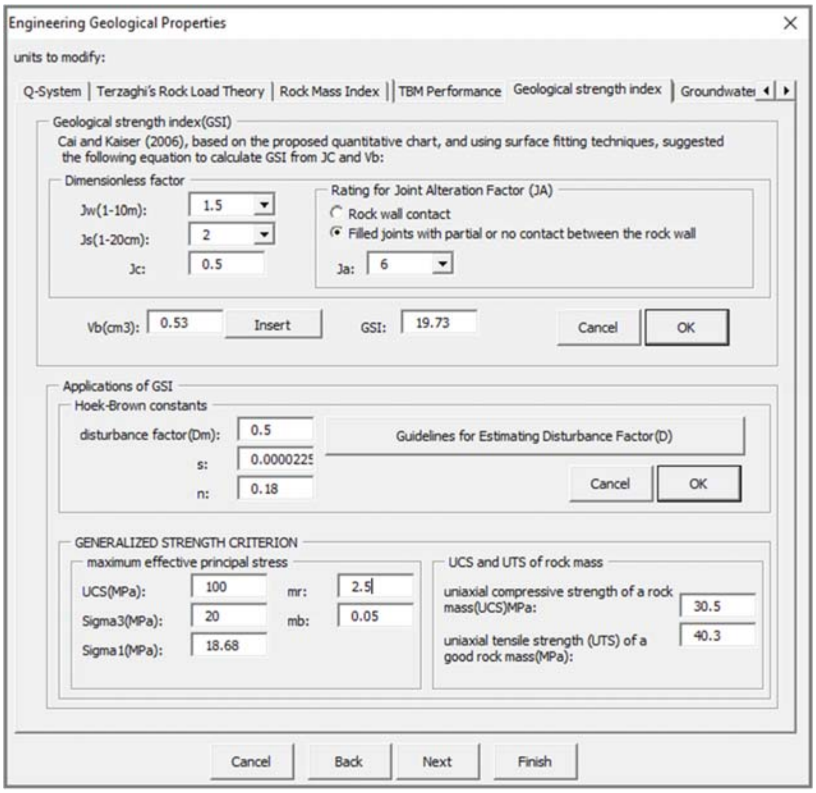



Fig. 12 GSI classification (GSI), and applied parameters calculated based on GSI value

TABLE V
INPUT PARAMETERS AND RMR DETERMINATION

| Units | RMR | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RMR parameters rating | | | | | | | | | | | RMR |
| | | | | Joint condition | | | | | Joint orientation | | | |
| | RQD Rating | UCS Rating | Spacing of Discontinuities | Discontinuity length | Separation (aperture) | Roughness of discontinuity surface | Infillings (gouge) | Weathering discontinuity surface | General description | Rating | Tunnel Rating | |
| unit1 | 17 | 7 | 10 | 6 | 6 | 6 | 4 | 5 | Dripping | 4 | -2 | 59 |
| unit2 | 20 | 7 | 10 | 2 | 1 | 6 | 4 | 5 | Wet | 7 | 0 | 62 |
| unit3 | 20 | 12 | 8 | 4 | 5 | 6 | 4 | 6 | Damp | 10 | -2 | 73 |
| unit4 | 17 | 7 | 8 | 4 | 6 | 5 | 4 | 5 | Wet | 7 | 0 | 63 |
| unit5 | 20 | 7 | 8 | 4 | 6 | 5 | 2 | 5 | Damp | 10 | 0 | 67 |
| unit6 | 20 | 12 | 15 | 2 | 5 | 5 | 4 | 5 | Damp | 10 | -2 | 76 |
| unit7 | 20 | 7 | 8 | 4 | 5 | 5 | 4 | 5 | Damp | 10 | -2 | 66 |
| unit8 | 20 | 7 | 15 | 4 | 5 | 5 | 2 | 5 | Wet | 7 | -5 | 65 |
| unit9 | 3 | 4 | 8 | 4 | 5 | 5 | 2 | 5 | Wet | 7 | -5 | 38 |

TABLE VI
OUTPUT PARAMETERS AND RMR APPLICATIONS

| Units | Applications of RMR | | | | | |
|---|---|---|---|---|---|---|
| | Classification of rock mass | Average stand-up time | Cohesion of rock mass (MPa) | Angle of internal friction of rock mass | Allowable bearing pressure (T/m$^2$) | Safe cut slope |
| unit1 | Fair | 1 week for v | 0.2-0.3 | 25-35 | 280-135 | 55 |
| unit2 | Good | 1 year for 10 m span | 0.3-0.4 | 35-45 | 440-280 | 65 |
| unit3 | Good | 1 year for 10 m span | 0.3-0.4 | 35-45 | 440-280 | 65 |
| unit4 | Good | 1 year for 10 m span | 0.3-0.4 | 35-45 | 440-280 | 65 |
| unit5 | Good | 1 year for 10 m span | 0.3-0.4 | 35-45 | 440-280 | 65 |
| unit6 | Good | 1 year for 10 m span | 0.3-0.4 | 35-45 | 440-280 | 65 |
| unit7 | Good | 1 year for 10 m span | 0.3-0.4 | 35-45 | 440-280 | 65 |
| unit8 | Good | 1 year for 10 m span | 0.3-0.4 | 35-45 | 440-280 | 65 |
| unit9 | Poor | 10 hours for 2.5 m span | 0.1-0.2 | 15-25 | 185-45 | 45 |

TABLE VII
INPUT PARAMETERS AND Q DETERMINATION

| Units | Rock mass quality (Q-System) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Input parameters | | | | | | | | | Q | Rock mass number (RMN) |
| | Q-System parameters rating | | | | | | | | | | |
| | Joint Set Number (Jn) | Joint Roughness Number (Jr) | Joint Alteration Number (Ja) | Joint Water Reduction Factor (Jw) | SRF | RQD (%) | UCS (MPa) | H (m) | B (m) | | |
| unit1 | 12 | 2 | 2 | 0.66 | 5 | 83 | 70 | 3.25 | 1.5 | 0.91 | 4.57 |
| unit2 | 12 | 2 | 2 | 0.5 | 5 | 94 | 80 | 3.48 | 1.7 | 0.78 | 3.9 |
| unit3 | 9 | 4 | 0.75 | 0.66 | 5 | 97 | 120 | 3.17 | 1.47 | 7.62 | 38.11 |
| unit4 | 12 | 1.5 | 3 | 0.5 | 5 | 87 | 60 | 3.48 | 1.7 | 0.36 | 1.82 |
| unit5 | 9 | 1.5 | 3 | 0.5 | 5 | 94 | 70 | 3.17 | 1.47 | 0.52 | 2.61 |
| unit6 | 12 | 3 | 1 | 0.5 | 5 | 100 | 100 | 2.79 | 1.24 | 2.5 | 12.5 |
| unit7 | 12 | 2 | 2 | 0.5 | 5 | 97 | 90 | 2.57 | 3.12 | 0.81 | 4.04 |
| unit8 | 12 | 2 | 2 | 0.5 | 5 | 100 | 60 | 5.2 | 3.94 | 0.83 | 4.17 |
| unit9 | 12 | 2 | 2 | 0.66 | 10 | 16 | 40 | 6.45 | 4.8 | 0.09 | 0.88 |

TABLE VIII
OUTPUT PARAMETERS AND Q APPLICATION

| Units | Applications Of Q-System | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Estimation of support pressure | | | Estimation of Support System | | | | | Cohesion and Angle of Internal Friction | | Modulus of Deformation of Rock Mass (MPa) Ed | in situ permeability (k) of rock mass (GPa) |
| | The number of joint sets is there | | | Unsupported Span | | Design of Supports | | | | | | |
| | | | | | | | Anchor Length (la) | | | | | |
| | Wall Factor (Qw) | ultimate roof support pressure (Pv) MPa | ultimate wall support pressure (Ph) MPa | Values of Excavation Support Ratio (ESR) | Equivalent Dimension (De)m | Bolt Length (lb) | In Roof (m) | In Walls (m) | cp (MPa) | PHip (degrees) | | |
| unit1 | 4.55 | 0.1 | 0.06 | 1 | 0.5 | 2.22 | 0.6 | 1.14 | 0.97 | 28 | 8.62 | 0.0000072 |
| unit2 | 3.9 | 0.11 | 0.06 | 1 | 0.5 | 2.26 | 0.68 | 1.22 | 1.25 | 31 | 8.56 | 0.000003 |
| unit3 | 38.1 | 0.03 | 0.02 | 1 | 0.5 | 2.22 | 0.59 | 1.11 | 2.6 | 74 | 20.76 | 0.000001 |
| unit4 | 1.8 | 0.19 | 0.11 | 1 | 0.5 | 2.26 | 0.68 | 1.22 | 0.87 | 17 | 6.03 | 0.00005 |
| unit5 | 2.6 | 0.17 | 0.1 | 1 | 0.5 | 2.22 | 0.59 | 1.11 | 1.46 | 17 | 7.16 | 0.000015 |
| unit6 | 12.5 | 0.05 | 0.03 | 1 | 0.5 | 2.19 | 0.5 | 0.98 | 1.67 | 56 | 13.53 | 0.0000085 |
| unit7 | 4.05 | 0.11 | 0.06 | 1 | 0.5 | 2.47 | 1.25 | 0.9 | 1.45 | 26 | 9.01 | 0.000002 |
| unit8 | 4.15 | 0.11 | 0.06 | 1 | 0.5 | 2.59 | 1.58 | 1.82 | 1 | 33 | 7.94 | 0.00001 |
| unit9 | 0.45 | 0.22 | 0.13 | 1 | 0.5 | 2.72 | 1.92 | 2.26 | 0.05 | 33 | 3.34 | 0.0003 |

The input parameters used for calculating include general features of tunnel such as shape, length, width, height or diameter, and slope, the number and position of the engineering geological units. Intact rock properties comprise the results of fundamental field tests, including the Schmidt hammer rebound number (MPa), point load strength index (MPa), and index manual test (MPa). Additionally, the results of laboratory tests, such as porosity, density, unconfined compressive strength (UCS), and tensile strength, are included. Discontinuity properties encompass the number and type of joint sets, orientation, joint surface condition (including weathering, roughness, aperture, filling, and wall strength), spacing, and persistence. By importing the input parameters and running the software, all the output parameters can be automatically calculated. In this regard, users will be able to utilize these output parameters in the design stage of tunnel projects. Some of these output parameters include the engineering parameters of the rock mass, such as the rock mass strength (UCS), the modulus of deformation of the rock mass (Ed, GPa), the in-situ permeability of the rock mass (K, cm/sec), and cohesion and angle of internal friction.

TABLE IX
GSI CLASSIFICATION SYSTEM

| Units | GSI | | | | | |
|---|---|---|---|---|---|---|
| | Input parameters | | | | | |
| | Dimensionless factor (Jc) | | | | Vb (cm$^3$) | GSI |
| | Jw (1-10 m) | Js (1-20 cm) | Jc | Joint Alteration Factor (JA) Rock wall contact | | |
| unit1 | 3 | 3 | 4.5 | 2 | 0.42 | 37.28 |
| unit2 | 3 | 3 | 4.5 | 2 | 0.5 | 37.58 |
| unit3 | 3 | 3 | 12 | 0.75 | 0.58 | 45.52 |
| unit4 | 3 | 2 | 3 | 2 | 0.38 | 33.89 |
| unit5 | 3 | 2 | 3 | 2 | 0.48 | 34.29 |
| unit6 | 3 | 2 | 6 | 1 | 0.99 | 41.12 |
| unit7 | 3 | 2 | 3 | 2 | 0.63 | 34.76 |
| unit8 | 3 | 2 | 6 | 1 | 0.8 | 40.72 |
| unit9 | 3 | 2 | 3 | 2 | 0.09 | 31.54 |

TABLE X
OUTPUT PARAMETERS AND GSI APPLICATIONS

| Units | Applications of GSI | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Hoek-Brown constants | | | maximum effective principal stress | | | | | UCS and UTS of rock mass | |
| | disturbance factor (Dm) | S | n | UCS (MPa) | Sigma3 (MPa) | mr | mb | Sigma1 (MPa) | UCS of a rock mass (UCS) MPa | uniaxial tensile strength (UTS) of a good rock mass (MPa) |
| unit1 | 0.5 | 0.00023 | 0.06 | 70 | 40 | 13 | 0.66 | 108.09 | 42.38 | -0.02 |
| unit2 | 0.5 | 0.00024 | 0.05 | 80 | 50 | 17 | 0.87 | 156.43 | 52.77 | -0.02 |
| unit3 | 0.5 | 0.0007 | 0.03 | 120 | 85 | 21 | 1.57 | 392.84 | 96.5 | -0.05 |
| unit4 | 0.5 | 0.0001 | 0.07 | 60 | 35 | 8 | 0.34 | 51.26 | 32.37 | -0.03 |
| unit5 | 0.5 | 0.00015 | 0.07 | 70 | 45 | 10 | 0.44 | 94.81 | 37.91 | -0.02 |
| unit6 | 0.5 | 0.00038 | 0.04 | 100 | 60 | 9 | 0.55 | 169.68 | 73.05 | -0.07 |
| unit7 | 0.5 | 0.00016 | 0.07 | 90 | 60 | 9 | 0.4 | 121.59 | 48.95 | -0.04 |
| unit8 | 0.5 | 0.00036 | 0.04 | 60 | 38 | 9 | 0.53 | 104.33 | 43.74 | -0.04 |
| unit9 | 0.5 | 0.0001 | 0.08 | 40 | 34 | 7 | 0.27 | 52.64 | 19.27 | -0.02 |

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