TunnelEase: A Creative Approach to Tunneling Support Design Through the Development of an Android Application Incorporating RMR, RSR, and Q-System Methodologies

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Abstract

Tunneling construction plays a critical role in underground infrastructure projects, especially for transportation, environmental, and urban development. The integrity of tunnels is paramount to the success of these projects. The current study introduces TunnelEase, an innovative Android application designed to assist in estimating geological conditions and providing recommendations during the initial phase of tunneling support design. The mobile application integrates three widely used rock mass classification systems: Rock Mass Rating (RMR), Rock Structure Rating (RSR), and the Q-System. Developed using Android Studio, the application simplifies the complex calculations involved in rock mass classification by incorporating numerical ratings. This enables the engineers to conduct evaluations in a quick and precise manner. Performance of the application was validated by means of comparison of the results of RMR, RSR and Q-System in MS Excel where the application was proven to be correct and efficient. TunnelEase is optimized in remote locations, where the availability of internet connection can be limited, and will further safety, simplifying construction work, and benefiting rural application use. This tool serves as a very positive input in ground engineering in the contemporary field of tunnelling.

Keywords: Android application; rock mass classification; RMR; RSR; Q; tunneling support design.

1. Introduction

Tunnel construction presents numerous challenges due to the inherent variability of geological conditions. Rock mass is a dynamic and uncertain medium in rock engineering and in tunnel construction stability of the ground is largely dependent on geological conditions as well as tunnel properties [1]. Ensuring the selection of appropriate support systems is critical for maintaining stability and minimizing risks associated with ground movement and tunnel collapse [2].

Traditional methods of tunneling support design rely on manual classification using systems such as the Rock Mass Rating (RMR), Rock Structure Rating (RSR), and the Q-System. Under the South African Council of 1973, the RMR system was made by Z.T. Bieniawski as one of the initial tools in assessing rock masses [3]. Widely applicable in the field of engineering, the Rock Mass Rating (RMR) system was created so that rock masses could be classified and a preliminary stability could be determined to design the system of the support of the tunnels [4-5]. Another

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commonly used system is the Rock Structure Rating (RSR) system developed by Wickham et al. 1972, which was proposed to measure the quality of a rock mass and to decide on adequate support to the underground activities [6]. The Rock Mass Rating (RMR) system is widely used in engineering to classify rock masses and assess initial stability for tunneling support system design [4-5]. The Rock Structure Rating (RSR) system, developed by Wickham et al. (1972), is used to assess rock mass quality and determine the appropriate support for underground projects [6]. This method considers multiple factors, helping engineers select suitable support systems and ensure safety. The Tunnelling Quality Index (Q) system, introduced by Barton et al. in 1974 [7], integrates multiple variables to assess rock mass quality and offers recommendations for advanced tunnel reinforcement, such as bolts and shotcrete [8]. The Q-system has been widely applied in studies, including those focusing on rock mass stability with cement grouting [9]. These three classification systems, RMR, RSR, and Q is the foundation of the current research effort.

In the present world, technology plays a significant role in routine life across the globe. Smartphones are common and widely used devices in digital media. These devices simplify multiple comprehensive tasks by optimizing processes, especially in communication, information, and calculation [10]. Now, there are more than 3.6 billion smartphones internationally, with the market growing at an annual rate of approximately 8% [11]. In the presence of multiple operating systems, Android operating system stands out due to its user-friendly interface, affordability, and versatility. Android smartphones can easily support a wide range of applications, provided the device meets the necessary specifications to ensure smooth operation without errors [11].

The purpose of this research is to develop and evaluate the TunnelEase Android application to estimate preliminary geological stability and recommend appropriate provisions, including waterproofing techniques, for tunnels based on rock mass quality and rating. The application will leverage these ratings to provide accurate assessments and tailored recommendations. TunnelEase distinguishes itself by integrating RMR, RSR, and Q-System methodologies into a mobile platform, enabling real-time field assessments without the need for manual spreadsheet calculations. This approach enhances efficiency, improves accuracy, and increases accessibility for field engineers. To further emphasize its uniqueness, a brief comparative analysis is presented. TunnelEase is designed to work seamlessly offline, ensuring uninterrupted real-time field assessments even in areas with no internet connectivity. This addition will underscore TunnelEase's innovative contribution to the industry. By combining advanced geotechnical principles with modern technology, TunnelEase aims to streamline decision-making, save time in tunnel construction, enhance the evaluation of geological conditions, and effectively address challenges in tunneling support design and water management.

2. literature Review:

2.1. Rock Mass Rating (RMR)

The Rock Mass Rating (RMR) system was primarily introduced by Z.T. Bieniawski in 1973 [12]. Since its development, the system has evolved through extensive revisions and updates, becoming a comprehensive and practical evaluation tool. The RMR systems generally consider six parameters for each structural domain to assign the rock mass [13].

- Uniaxial Compressive Strength (UCS)
- Rock Quality Designation (RQD)
- Spacing of Discontinuities
- Condition of Discontinuities
- Groundwater Conditions
- Orientation of Discontinuities

The addition of all six factors rating values can be calculated by Equation 1.

$$RMR=R_1+R_2+R_3+R_4+R_5+R_6 \quad (1)$$

Where R_1 = rating of UCS, R_2= rating of RQD, R_3= rating of spacing of discontinuities, R_4= rating of Condition of Discontinuities, R_5= rating of Groundwater Conditions, R_6= rating of Orientation of Discontinuities.

The evaluated ratings of classification in RMR of each parameter are given in Table 1. RMR values are used to classify the rock masses, ranging from high to low-quality rock. Rock mass classification ratings with descriptions are given in Table 2.

Table 1. Classification parameters in RMR system by. (Z.T. Bieniawski et al 1973)

Classification parameters and their ratings								
Parameter	**Ranges of values**							
Strength of intact rock material (MPa)	UCS	>250 MPa	100-250 MPa	50-100 MPa	25-50 MPa	5-25 MPa	1-5 MPa	<1 MPa
Ratings (R1)		15	12	7	4	2	1	0
Drill Core Quality	RQD	90%-100%	75-90%	50-75%	25-50%	<25%		
Ratings (R2)		20	17	13	8	3		
Space of discontinuities (m)		>2	0.6-2	0.2-0.6	0.06-0.2	<0.06		
Ratings (R3)		20	15	10	8	5		
Condition of discontinuities		Very rough surfaces not continuous No separation Unweathered wall rock	Slightly rough surfaces separation <1mm slightly weathered walls	Slightly rough surfaces separation <1mm highly weathered walls	Slickened surfaces or gouge 5mm thick or separation 1-5 mm continuous	Soft gouge >5mm thick or separation >5mm continuous		
Ratings (R4)		30	25	20	10	0		
Groundwater	General Condition	Completely dry	Damp	Wet	Dipping	Flowing		
Rating (R5)		15	10	7	4	0		
Strike and dip orientation	Tunneling and mines	Very Favourable	Favourable	Fair	Unfavourable	Very unfavourable		
Rating (R6)		0	-2	-5	-10	-12		

Table 2. RMR rating classes by (Z.T. Bieniawski et al. (1973)

RMR Rating	Class Number	Description
81-100	I	Very good rock
61-80	II	Good rock
41-60	III	Fair rock
21-40	IV	Poor rock
<21	V	Very poor rock

2.2 Rock Structure Rating:

The Rock Structure Rating (RSR) was first developed by Wickham et al. (1972) for the assessment of rock quality and determining the appropriate support system based on their RSR classification.

The system classifies rock hardness into four categories: hard, medium, soft, and decomposed with basic types of rock igneous, metamorphic, and sedimentary. A relationship between rock hardness and uniaxial compressive strength (UCS) is established. In fact, the geotechnical engineering classification of intact rock by Deere and Miller (1966) was used [3].

The importance of the RSR system ratings of each parameter is outlined below, which are in addition the numerical values for RSR in Equation 2.

$$RSR = \text{Parameter A} + \text{Parameter B} + \text{Parameter C} \quad (2)$$

1. Parameter A, Geology:

- The origin of the rock type

- The hardness of the Rock
- Geological structure

2. Parameter B, Geometry:
- The spacing of joints.
- The orientation of joints
- The tunnel excavation.
3. Parameter C: physical condition
- The overall quality is based on the combination of geology and geometry.
- The position of the joints.
- The amount of groundwater permeable.

The RSR system originally utilized numerical values. The methodological details are outlined in these three significant tables, study is presented as Tables 3, 4, and 5. These tables are used to assess the points for all RSR parameters.

Table 3. Rock Structure Rating (RSR) Parameters A: Geology by Wickham et al. (1972)

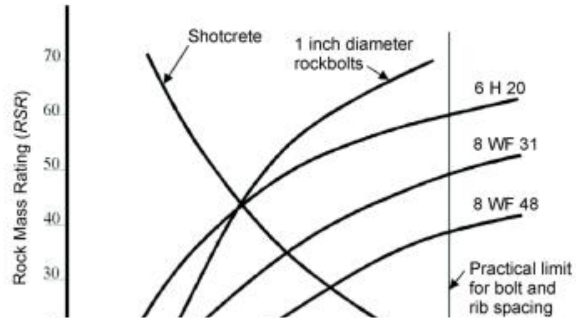
Basic Rock Type / Geological Structure	Hard	Medium	Soft	Decomposed	Massive	Slightly Folded or Faulted	Moderately Folded or Faulted	Intensively Folded or Faulted
Igneous	1	2	3	4				
Metamorphic	1	2	3	4				
Sedimentary	2	3	4	4				
Type 1					30	22	15	9
Type 2					27	20	13	8
Type 3					24	18	12	7
Type 4					19	15	10	6

Table 4. Rock Structure Rating (RSR) Parameters B: Geometry by Wickham et al. (1972)

<table>
<tr><th rowspan="2">Anticipated water inflow gpm/1000ft of Tunnel</th><th colspan="6">Geological Condition</th></tr>
<tr><th colspan="6">Parameter A (13-44) | Parameter B (45-75)</th></tr>
<tr><td>Condition</td><td>Good</td><td>Fair</td><td>Poor</td><td>Good</td><td>Fair</td><td>Poor</td></tr>
<tr><td>None</td><td>22</td><td>18</td><td>12</td><td>25</td><td>22</td><td>18</td></tr>
<tr><td>Sligth, <200 gpm</td><td>19</td><td>15</td><td>9</td><td>23</td><td>19</td><td>14</td></tr>
<tr><td>Modern, 200-1000 gpm</td><td>15</td><td>22</td><td>7</td><td>21</td><td>16</td><td>12</td></tr>
<tr><td>Heavy, >1000 gpm</td><td>10</td><td>8</td><td>6</td><td>18</td><td>14</td><td>10</td></tr>
</table>

Table 5. Rock Structure Rating (RSR) Parameter C: physical condition by Wickham et al. (1972)

RSR support guidance and the selection of suitable tunnel support based on the rock mass's RSR value are presented in Figure 1. Lower RSR values need stronger support like rock bolts and shotcrete, while higher RSR values may require lighter support.



Average joint spacing	Strike Prependicular to Axis					Strike Parallel to Axis		
	Direction of Derive					Direction of Drive		
	Both	With Dip		Against Dip		Either Direction		
	Flat	**Dipping**	**Vertical**	**Dipping**	**Vertical**	**Flat**	**Dipping**	**Vertical**
Very closely jointed, < 2 in	9	11	13	10	12	9	9	7
Closely jointed, 2-6 in	13	16	19	15	17	14	14	11
Moderately jointed, 6-12 in	23	24	28	19	22	23	23	19
Moderate to blocky, 1-2 ft	30	32	36	25	28	30	28	24
Blocky to massive, 2-4 ft	36	38	40	33	35	36	24	28
Massive, >4 ft	40	43	45	37	40	40	38	34

Figure 1. RSR support estimation

2.3 Tunnelling Quality Index (Q) system

The Q-system was developed by Barton et al. in 1974, because of approximately 200 case studies involving tunnels and caverns [14]. Studies have demonstrated that the Q-system is an effective method for assessing tunnel support design. RMR and Q-System use similar approaches but different mathematical aspects, Q-System factors combined into product [15], while RMR is the addition sequence of their factors. Q-System is developed by their six factors in the quotient form in Equation 3.

$$Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{Jw}{SRF} \quad (3)$$

Where,

- RQD is the factor of Rock quality designation factor).
- Jn is (Joint set number factor).
- Jr, is (Joint roughness number factor).
- Ja, is (Joint alteration factor).
- Jw, is (Joint water reduction factor).
- SRF is (Stress reduction factor).

The Q-System evaluation distributed into three quotients. (RQD/Jn) fraction represents rock mass geometry, (Jr/Ja) measures the joint roughness and joint alteration, and (Jw/SRF) indicates the stress and water condition.

Table 6 (a). Rock Quality Designation (RQD) by Barton et al. (1974)

Rock Quality Designation	RQD Range
Very Poor	0-25
Poor	25-50
Fair	50-75
Good	75-90
Excellent	90-100

Table 6 (b). Joint set number factor (Jn) by Barton et al. (1974)

Joint Set Number	Jn
Massive, no or few joints	0.5-1
One joint set	2
One joint set plus random joints	3
Two joint sets	4
Two joint set plus random joints	6
Three joint set	9
Three joint set plus random joints	12
Four or more joint sets, heavily jointes	15
Crushed rock, earthlike	20

Table 6(c). Joint roughness number factor **(**Jr) by Barton et al. (1974)

Joint Roughness Number	Jr
(a) Rock-wall contact, (b) Rock wall contact before 10 cm shear	
Discoutinous joints	4
Rough or irregular, undulating	3
Smooth, undulating	2
Slickensided, undulating	1.5
Rough or irregular, planar	1.5
Smooth, planar	1
Slickensided, Planar	0.5
(c) No Rock-wall contact when shared	
Zone containing clay minerals thick enough to prevent rock-wall contact	1
Sandy, gravelly or crushed zone thick enough to prevent rock-wall contact	1

Table 6(d). Joint alteration factor (Ja) by Barton et al. (1974)

Description of Joint Alteration Number	Friction Angle Approx. (degrees)	Ja
(a) Rock-wall contact (no mineral fillings, only coatings)		
(b) Rock-wall contact before 10 cm shear (thin mineral fillings)		
Sandy particles, clay-free disintegrated rock, etc.	25 – 30°	4.0
Strongly over-consolidated non-softening clay mineral fillings (continuous, but < 5 mm thickness)	16 – 24°	6.0
Medium or low over-consolidated softening clay mineral fillings (continuous, but < 5 mm thickness)	12 – 16°	8.0
Swelling-clay fillings, i.e., montmorillonite (continuous, but < 5 mm thickness). Value of Ja depends on the percent of swelling clay size particles, and access	6 – 12°	8 – 12
(c) No Rock-wall contact when sheared (thick mineral fillings)		
Zones or bands of disintegrated or crushed rock and clay (see G, H, J for description of clay condition)	6 – 24°	6, 8, or 8-12
Zones or bands of silty- or sandy-clay, small clay fraction (non-softening)		5
Thick, continuous zones or bands of clay (see G, H, J for clay condition description)	6 – 24°	10, 13, or 13 – 20

Table 6(e). Joint water reduction factor (Jw) by Barton et al. (1974)

Table 6 (f1). Stress Reducing Factor (SRF) by Barton et al. (1974)

Description of joint Reducing Factor	Water Pressure (Kg/cm ^{2})	Jw
Dry excavation or minor inflow, i.e., <5 l/min locally	<1	1
Medium inflow or pressure, occasional outwash of joint fillings	1-2.5	0.66
Large inflow or high pressure in competent rock with unfilled joints	2.5-10	0.5
Large inflow or high pressure, considerable outwash of joint fillings	2.5-10	0.33
Exceptionally high inflow or water pressure at blasting, decaying with time	>10	0.1-0.2
Exceptionally high inflow or water pressure continuing without noticeable decay	>10	0.05-0.1

Description of Stress Reduction Factor	SRF
(a) Weakness zones interesting excavation, which cause loosening of rock mass when tunnel is excavated	
Multiple occurrences of weakness zones containing clay or chemically disintegrated rock, very loose surrounding rock (any depth)	10
Single weakness zone containing clay or chemically disintegrated rock (Depth of excavation ≤ 50 m)	5
Single weakness zone containing clay or chemically disintegrated rock (Depth of excavation > 50 m)	2.5
Multiple shear zones in competent rock (clay-free) (Depth of excavation ≤ 50 m)	7.5
Single shear zone in competent rock (clay-free) (Depth of excavation ≤ 50 m)	5
Single shear zone in competent rock (clay-free) (Depth of excavation > 50 m)	2.5
Loose, open joint, heavily jointed (any depth)	5

Table 6 (f2). Stress Reducing Factor (SRF) by Barton et al. (1974)

Description	σ_c / σ_1	θ_e / σ_c	SRF
(b) Competent rock, rock stress problems			
Low stress, near surface, open joints	200	< 0.01	2.5
Medium stress, favorable stress condition	200 – 10	0.01 – 0.03	1
High stress, very tight structure. Usually favorable to stability, more favorable to wall stability.	10 – 5	0.3 – 0.4	0.5 – 2
Moderate slabbing after > 1 hour in massive rock	5 – 3	0.5 – 0.65	5 – 50
Slabbing and rock burst after a few minutes in massive rock	3 – 2	0.65 – 1	50 – 200
Heavy rock burst (strain-burst) and immediate dynamic deformation in massive rock	< 2	> 1	200 – 400
(c) Squeezing rock: plastic flow in incompetent rock under the influence of high rock pressure		**θ_e / σ_c**	**SRF**
Mild squeezing rock pressure		1 – 5	5 – 10
Heavy squeezing rock pressure		5	10 – 20
(d) Swelling rock: chemical swelling activity depending on presence of water			**SRF**
Mild swelling rock pressure			5 – 10
Heavy swell rock pressure			10 – 15

To assess the effectiveness of the proposed support system, the capacity of the support system can also be evaluated. The Design Chart of Reinforcement support recommendations based on tunnel conditions, including options like rock bolts, shotcrete, or steel sets in Figure 2

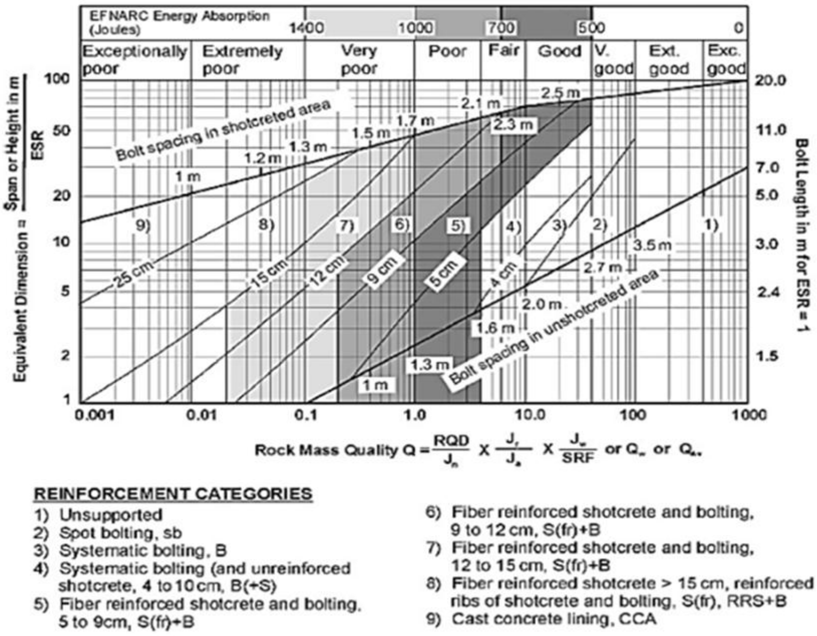


Figure 2. Design Chart of Reinforcement support

3. Android Application Development:

3.1 Methodology:

TunnelEase Android Application is developed by different environment programs. For desktop software development, Python with Tkinter library is used to create a user-friendly Graphical User Interface (GUI). Implementation of Custom python algorithms for calculating the RMR, RSR, and Q values. For mobile app development, Java is used as the main programming language, with the coding and deployment operated through Android Studio version 2024. For the development and deployment of Android devices. To handle geological data efficiently, SQLite will be utilized as a database solution. The external libraries will be incorporated to enhance the User interface, optimize data processing, and potentially enable API connections for data integration and sharing.

3.2 App Features:

TunnelEase Android Application is designed with a feasible interface with the dropdown options for inputting the parameter rating points, perform instant calculations and output results display to see in real-time. This application maintains consistency in use across any complex platform by offering the same features and the outcome results. Offering offline capabilities, with multiple functions, and calculations, to be accessible without internet connection sources. This is very beneficial especially in rural constructional areas due to the lack of internet services.

Interface Snapshots:

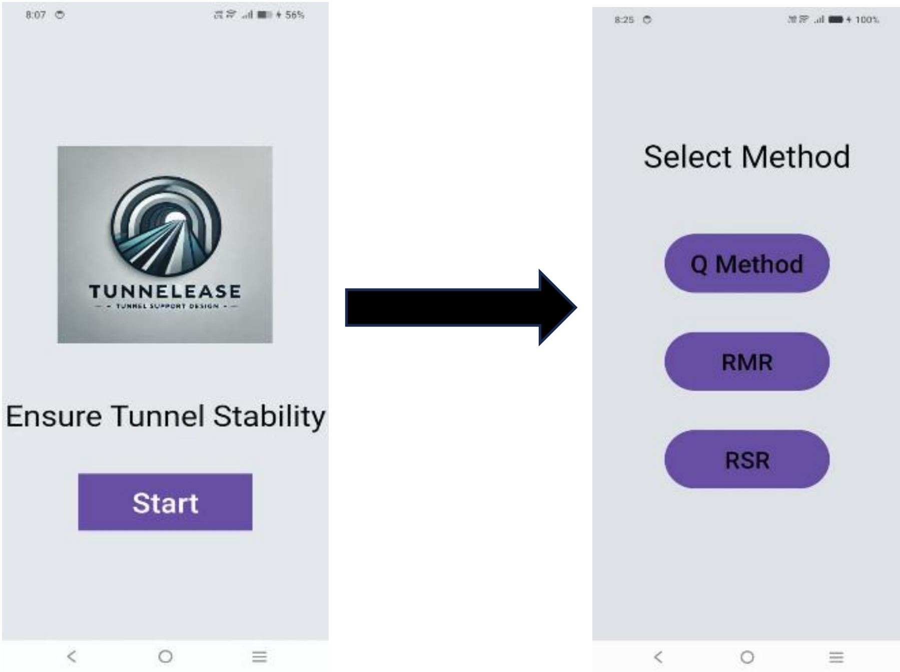


Figure 3. User-Interface of TunnelEase application.

4. Application Examination:

The examination phase of TunnelEase has garnered positive response, highlighting its ease of use, faster calculations, and reduced manual effort compared to traditional methods. By inputting the random parameters of these three methods and working app accurately. Examination of the application ensures accuracy and effectiveness in processing calculating logic. The correct calculation results are validated by comparing the development application with table manual calculations from MS Excel sheet. MS Excel is a logical program that is calculated across the globe. The validation of TunnelEase was conducted by comparing its RMR, RSR, and Q-System calculations with MS Excel, using their respective mathematical relations for parameter evaluation. The results were identical, confirming accuracy with no observed discrepancies. The application's results matched perfectly with the MS Excel sheet presented in the comparison in Table 7. TunnelEase application evaluates rock stability and suggests support criteria as per design requirements, ensuring efficient and reliable solutions for tunnel construction shown in Figure 4.

Table 7. Comparison results of RMR, RSR, Q-System by using random rock mass classification

RMR-Classification				
Parameters	**Ranges**	**Ratings**	**Excel Calculations**	**TunnelEase**
UCS (R1)	130 MPa	12	12	↓
RQD (R2)	80%	17	17	
Space of Discontinuities (R3)	1m	20	20	
Condition of Discontinuities (R4)	Slightly rough surfaces separation <1mm slightly weathered walls	25	25	
Ground Water (R5)	Damp	10	10	

Strike and Dip Orientation (R6)	Very unfavorable	-12	-12	
By Using RMR Parameters Mathematical Relation	(R1+R2+R3+R4+R5+R6)			
RMR=			**72**	**72**

RSR- Classification				
Parameters	**Ranges**	**Ratings**	**Excel Calculation**	**TunnelEase**
Geological Rating (R1)	Hard rock, slightly folded	30	30	
Geometrical Rating (R2)	Blocky to massive 2-4 ft	36	36	s
Ground Water and joint Condition (R3)	None, good joint condition	25	25	
By using RSR Parameters Mathematical Relation	(R1+R2+R3)			
RSR =			**91**	**91**

Q-System Classification				
Parameter	**Ranges**	**Ratings**	**Excel Calculation**	**TunnelEase**
RQD (%)	70-90%	82.5	82.5	
Jn	Two joint set	4	4	
Jr	Rough and Irregular	3	3	
Ja	Unaltered Joint walls	1	1	
Jw	Dry excavation	1	1	
SRF	Heavy rock burst	15	15	
By using Q-System Parameters Mathematical Relation	(RQD/Jn*Jr/Ja*Jw/SRF)			
Q=			**4.13**	**4.13**

The Snapshots illustrate inputs and outputs for the design evaluation by using RMR, RSR, and Q-Systems. These methods classify outcome results and recommend the required support stability and waterproofing techniques. These calculation values are impressive proof of the accuracy and running process of the application with similar output with manual calculation in Excel sheet

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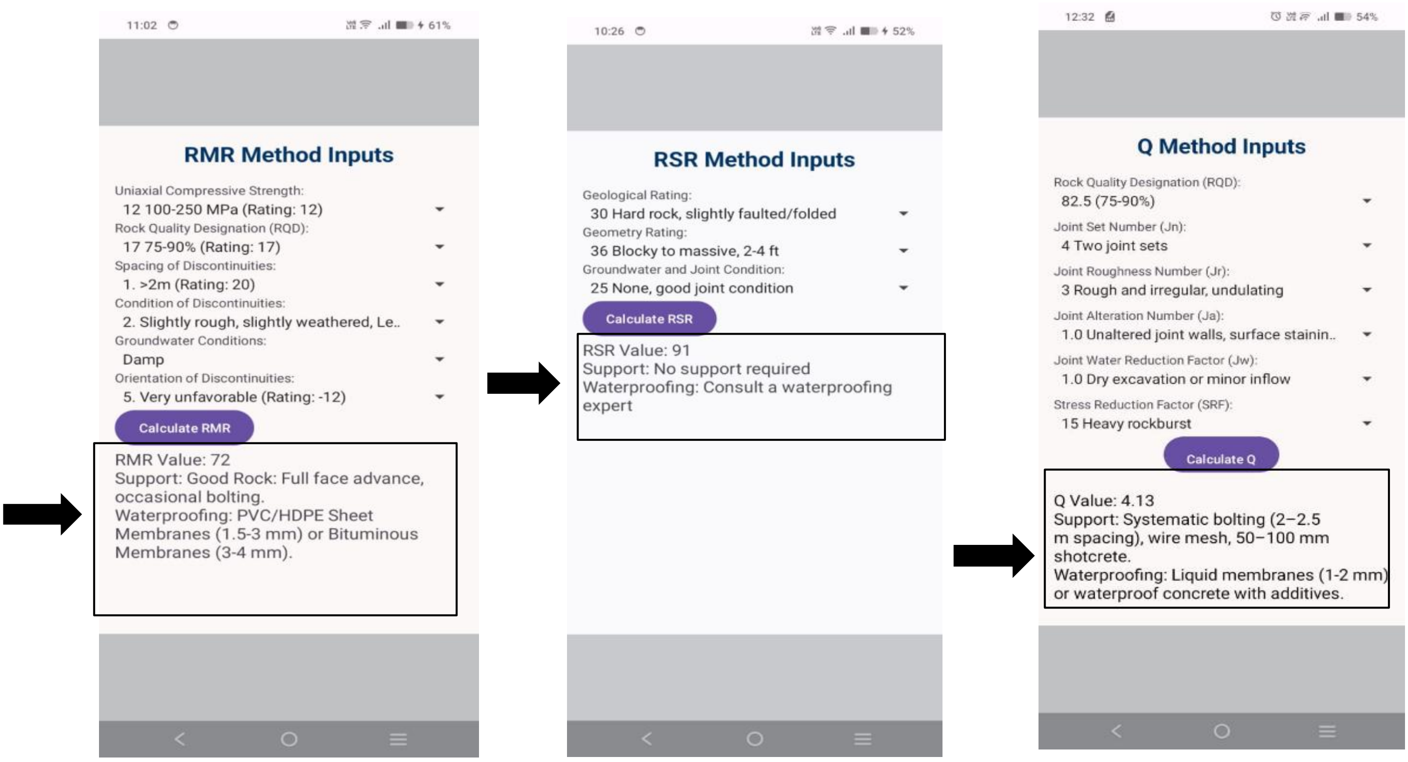

` (a) (b) (c)

Figure 4. RMR,RSR, and Q-System results of input random rock mass conditions with recommendations for suitable support and impermeability measures.

5. Conclusion:

The TunnelEase Android application has been presented and evaluated in current research, mobile application has the potential to transform tunneling support design by integrating the methodologies of RMR, RSR, and the Q-system into a user-friendly platform. By simplifying rock mass classification, it not only enhances the accuracy of assessments but also improves time efficiency, making it an invaluable tool for field investigations. TunnelEase ensures accurate and efficient tunneling assessments in all geological conditions without any limitations. Its offline functionality allows users to operate it anytime. In rural and remote areas, there is a lack of reliable internet connectivity. The application is highly functional with offline capabilities and safety in its exploitation is promoted, the efficiency of tunnels creation is raised due to the quick and correct pre-design of tunnel support which saves the manual labor and the time of engineering decision-making. The software combines the latest geotechnics with the existing technology and ensures the functionality and safety of the tunnel creation process.

Future development of this application will be addressed by increasing functionality of the application such as integrating additional rock mass classification tools such as GSI, RMN and RMi to make the application more versatile and adaptive. Tunnel Ease can contribute immensely to improvement in the tunneling practice in the underground sector and provide the engineers with the means which covers comprehensively effective cost effectiveness of designs in support systems. This efficient stable and support system analysis constitutes a subset of a broader demand that the traditional methods of carrying out these analyses are time consuming and labor intensive.

Utilization of sustainable inspection and appraisal instruments like TunnelEase is extremely important when it comes to augmenting safety in tunnels and eliminating chances of rock mass collapses. TunnelEase would enable engineers to develop tunneling projects and navigate through uncertainties in the future due to spatial integration and ability to lead the way with the information.

As a result of utilizing this application, engineers are able not only to make the construction of their tunnels more resistant and secure, but it is also their ability to extend the wellbeing of the entire society as they will have secure transportation systems and will have minimal risks on the environment.

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Abbreviations

The following abbreviations are used in this manuscript:

RMR	Rock mass rating
RSR	Rock structure rating
Q	Rock quality index
UCS	Uniaxial compressive strength
RQD	Rock quality designation
Jn	Joint set number
Jr	Joint roughness number
Ja	Joint alteration number
Jw	Joint water reduction factor
SRF	Stress reduction factor
RMN	Rock mass number
RMi	Rock mass index
GSI	Geological strength index

References

1. H. Rehman, W. Ali, A. M. Naji, J. J. Kim, R. A. Abdullah, and H. K. Yoo, "Review of rock-mass rating and tunneling quality index systems for tunnel design: Development, refinement, application and limitation," Appl. Sci., vol. 8, no. 8, 2018, doi: 10.3390/app8081250.
2. A. Rahmati, L. Faramarzi, and M. Sanei, "Development of a new method for RMR and Q classification method to optimize support system in tunneling," Front. Struct. Civ. Eng., vol. 8, no. 4, pp. 448–455, 2014, doi: 10.1007/s11709-014-0262-x.
3. R. Anbalagan, S. Bhawan, R. K. Puram, N. Delhi, C. Engineering, and I. I. T. Roorkee, "APPLICATION OF ROCK MASS CLASSIFICATION SYSTEMS FOR TUNNELING IN HIMALAYA, INDIA 1) Central Water Commission) Department of Earth Sciences, IIT Roorkee, Roorkee – 247 667, India ALIGNMENT 3 . ROCK MASS CLASSIFICATION," vol. 41, no. 3, pp. 1–6, 2004.
4. S. N. Warren, R. R. Kallu, and C. K. Barnard, "Correlation of the Rock Mass Rating (RMR) System with the Unified Soil Classification System (USCS): Introduction of the Weak Rock Mass Rating System (W-RMR)," Rock Mech. Rock Eng., vol. 49, no. 11, pp. 4507–4518, 2016, doi: 10.1007/s00603-016-1090-1.
5. P. Pantaweesak, P. Sontamino, and D. Tonnayopas, "Alternative software for evaluating preliminary rock stability of tunnel using rock mass rating (RMR) and rock mass quality (Q) on android smartphone," Eng. J., vol. 23, no. 1, pp. 95–108, 2019, doi: 10.4186/ej.2019.23.1.95.
6. W. H. Godwin, "Rock Mass Classification," no. 1972, pp. 795–796, 2018, doi: 10.1007/978-3-319-73568-9_244.
7. N. Barton, R. Lien, and J. Lunde, "Engineering Classification of Rock Masses for the Design of Tunnel Support.," 1974. doi: 10.1016/0148-9062(75)91319-4.
8. Z. T. Bieniawski, Classification of rock masses for engineering: the RMR system and future trends. Pergamon Press Ltd, 1993. doi: 10.1016/b978-0-08-042066-0.50028-8.
9. A. Zolfaghari, A. Sohrabi Bidar, M. R. Maleki Javan, M. Haftani, and A. Mehinrad, "Evaluation of rock mass improvement due to cement grouting by Q-system at Bakhtiary dam site," Int. J. Rock Mech. Min. Sci., vol. 74, pp. 38–44, 2015, doi: 10.1016/j.ijrmms.2014.12.004.
10. S. Lee, J. Suh, and H. dong Park, "Smart Compass-Clinometer: A smartphone application for easy and rapid geological site investigation," Comput. Geosci., vol. 61, pp. 32–42, 2013, doi: 10.1016/j.cageo.2013.07.014.

11. W. Chmielarz, “The usage of smartphone and mobile applications from the point of view of customers in Poland,” Inf., vol. 11, no. 4, 2020, doi: 10.3390/INFO11040220.
12. Y. Tong, Y. Yue, Z. Huang, L. Zhu, Z. Li, and W. Zhang, “Modified RMR Rock Mass Classification System for Preliminary Selection of Potential Sites of High-Level Radioactive Waste Disposal Engineering,” Sustain., vol. 14, no. 23, 2022, doi: 10.3390/su142315596.
13. E. Mert, S. Yilmaz, and M. Inal, “An assessment of total RMR classification system using unified simulation model based on artificial neural networks,” Neural Comput. Appl., vol. 20, no. 4, pp. 603–610, 2011, doi: 10.1007/s00521-011-0578-6.
14. A. K. Naithani, “Rock Mass Classification and Support Design using the Q-System,” J. Geol. Soc. India, vol. 94, no. 4, pp. 443–443, 2019, doi: 10.1007/s12594-019-1336-0.
15. “Geomechanical Classifications, Geotechnical Indexes, And Fractured Rock Media: The Influence Of Discontinuities On The Rock Masses Description,” Vol. 34, No. 4, Pp. 43–54, 2024, Doi: 10.59440/ceer/193932.