International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-6, March 2020

Characterization of Pare Rock Mass and Support System Design for Head Race Tunnel

Pragati Goswami, Diganta Goswami, Ranjeet Bahadur Singh, Pawan Kumar Singh, Sylvia Kashyap

Abstract: The Head Race Tunnel (HRT) of Pare Hydro-Electric Power Project in Arunachal Pradesh, India, traverses through the Upper-Siwalik Sub-Group of the Sub-Himalayan Range, exhibiting spatial heterogeneity with respect to geotechnical and geological properties. In such complex geological set up, consisting of bedding planes, joints, fractures,varied hydrological conditions etc., prediction of rock mass quality or the characterization of the rock massis a difficult task. Although challenging, it is important to predict the general response of the rock massto tunnel excavation. This paper attempts to characterize Pare Rock Mass around the HRT, based on Rock Quality Designation (RQD), Terzaghi's Rock Load Theory, Rock Structure Rating (RSR), Rock Mass Rating (RMR), and, Rock Mass Quality (Q) system. An attempt is also made to design the support system for HRT through Pare Rock Mass, based on these parameters. A critical examination of various support systems derived from the above mentioned methods and the support system actually provided at the HRT at Pare Hydroelectric Power Project is also presented in the paper. The study presented in this paper will providean insight about the suitability of a particular method in the design of support system in a rock mass similar to Pare rock mass.

Keywords: Pare Rock, Rock Mass Classification, Support design, Tunneling.

I. INTRODUCTION

Pare Hydroelectric Power Project, which is being executed by NEEPCO Ltd, at Pare, Arunachal Pradesh, India, is a run-of-the river scheme with a 78.0m high concrete gravity dam and a 7.5m diameter concrete lined modified Horse shoe shaped Headrace Tunnel (HRT), 2.83km long, along with other salient components. Geotechnical investigation prior to the construction of the HRT, and also during its excavation has given enough exposure for characterization of the rock mass. Various available and extensively used methods for assessing important parameters like stand-up time, and, designing support system for the HRT, such as, Deere's RQD, Terzaghi's Rock Load Theory, Rock Structure Rating (RSR), Bieniawski's Rock Mass Rating (RMR), Barton's Rock Mass Quality (Q) etc. [1],[2] are employed to arrive at a final design for the support system of HRT. The actual support system used for the HRT at Pare, which has been performing well, is compared with the ones obtained from the various other methods. The first part of the paper deals with characterization of the Pare rock mass by various available methods and the second part is devoted to the design of the support system of the HRT.

II. GEOLOGICAL FEATURE OF THE PROJECT SITE

Drill holes at the HRT site and the rock exposed during tunneling reveals that the rock mass is predominantly medium grained, salt pepper textured, soft, friable grayish sandstone. Because of presence of mega folds, faults and the thrust it has been experiencing, the landform shows presence of tectonic lineaments and heterogeneity in lithology.

Pare lies within the Upper-Siwalik Sub-Group of the Sub-Himalayan Range. Alternate lenses of pebbly sandstone and carbonaceous shale are observed within the weak to very weak, moderately to highly jointed sandstone with seepage face.

III. ROCK MASS CHARACTERIZATION OF PARE HRT ROCK

From the drill hole at the HRT site and also from the geological mapping for about 100m running distance during actual excavation of the HRT, characterization of the Pare HRT rock mass is done. Geological mapping was done at fifty sections during HRT excavation, and Table I shows one such sample description at achainage of 1198.7m in the HRT. Following sub-sections from A to E describe various approaches adopted for characterization and the sub section F shows the results of the rock mass characterization at HRT, Pare, Arunachal Pradesh.

Manuscript received on March 15, 2020.
Revised Manuscript received on March 24, 2020.
Manuscript published on March 30, 2020.

* Correspondence Author
Pragati Goswami*, Civil Engineering Department, Assam Engineering College, Guwahati, India. E-mail: pragatigoswami900@gmail.com
Diganta Goswami,Civil Engineering Department, Assam Engineering College, Guwahati, India. E-mail: digantagoswami2@gmail.com
Ranjeet Bahadur Singh, Civil Engineering Department, Assam Engineering College, Guwahati, India. E-mail: rbsinghntpc@gmail.com
Pawan Kumar Singh, Civil Engineering Department, Assam Engineering College, Guwahati, India. E-mail: singhpawank123@gmail.com
Sylvia Kashyap, Civil Engineering Department, Assam Engineering College, Guwahati, India. E-mail: sylvia.kashyap@gmail.com

Table- I: Description of Pare Rock Mass along HRT for Tunnel Chainage = 1198.70m

Tunnel Chainage (m)	Joint set	Rock Type	Strength	Weathering Condition	Aperture	Joint Spacing (cm)	Water Condition	UCS (MPa)	$J_{v\,min}$	J_{vmax}	Dir/Dip angle
1198.7	1	Sand stone	weak	unweathered	semi open	20-60	dripping	10-25	6.6667	2.1667	206°/72°
	2		very weak	slightly weathered	tight discontinuity	>60	wet	2-10			40°/22°

A. Rock QualityDesignation

Deere et. al. [3] defined the Rock Quality Designation (RQD) as a modified core recovery percentage in which the sound rock core pieces over 100mm are summed and divided by the length of core run. The core logging at the site gives an average RQD of 20. Rock Quality Designation (RQD) is the simplest method for assigning quality to rock. Since in many cases RQD is the only information available for describing rock discontinuities, determination of RQD is very important as it provides useful information for effective evaluation of the deformation modulus and unconfined compressive strength of rock masses based on RQD [5]. RQD is one of the important parameter in many of the rock mass classification systems such as Rock Structure Rating (RSR), Rock mass Rating (RMR), Rock Tunnel Quality Q-System, etc.

The RQD values can be obtained either from drill core or from empirical correlation between volumetric discontinuity frequency as proposed by Palmstrom (2005) and shown in (1) [4].

$$RQD = 110 - 2.5\,Jv \quad \text{for } Jv = 4 \text{ to } 44 \qquad (1)$$

Where, Jv = Volumetric Joint frequency

$$Jv = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} + \cdots \qquad (2)$$

Where S_1, S_2 and S_3 are the mean discontinuity set spacing.

While using (1), RQD is found to be close to 100, which is very high compared to the values obtained from core logging as per *Deere*, *1989*[5]. It may be concluded that, while using J_v, the aperture condition of having clay filling plays a major role while getting a correct RQD value. In further calculations RQD is taken to be 20 as obtained from core logging. The Pare rock has two to three joint sets with few random joints. Characterization of Pare Rock Mass is done as per Deere, 1968 [6], which defines rock classes based on RQD, and is presented in Table II.

B. Terzaghi's Rock Load Theory

Terzaghi in 1946 [7] classified a rock mass successfully for the design of tunnel support in his paper which was the earliest reference to the use of rock mass classification in which descriptive classification are estimated on the basis of the rock loads, carried by steel sets. Table III, exhibits calculation of Rock Load Factor (Hp) as per Terzaghi (1946) and derivation of the Rock Condition.

C. Rock Structure Rating (RSR) System

Rock Structure Rating (RSR) classification was first described by Wickham et al in 1972 [8]. It is a quantitative based method which is basically used for describing the quality of a rock mass and for selecting appropriate supports on the basis of their Rock Structure Rating. It is based on three parameters, for which ratings are given and added together to obtain the final value of RSR. Rock Structure Rating (RSR) of the Pare Rock Mass is derived and presented in Table IV.

D. Rock Mass Rating (RMR) System

Bieniawski (1979) [9] and Bieniawski (1993) [10] characterizes rock mass based on Rock Mass Rating (RMR) on the basis of six parameters such as Unconfined Compressive Strength (UCS), RQD, Spacing and Condition of discontinuities, Ground water condition and Orientation of the joints in the rock mass. Table V shows RMR and characterization of the Pare rock mass at chainage 1198.7m of the HRT.

E. Rock Mass Quality (Q) System

The Q-system of rock mass classification was originally proposed by Barton et. al. (1974) [11] and Barton (2002) [12] at the Norwegian Geotechnical Institute (NGI) and it is based on the number of case histories of tunnels and caverns. They defined the rock mass quality (Q) by the following influential factors:

$$Q = [RQD/J_n][J_r/J_a][J_w/SRF] \qquad (3)$$

Classification of Pare rock based on Q-System is presented in Table VI.

F. Results of Pare Rock Mass Characterization

The following tables present the characterization of Pare Rock Mass based on the above mentioned classification systems.

Retrieval Number: F9575038620/2020©BEIESP
DOI: 10.35940/ijrte.F9575.038620
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Table- II: Characterization of Pare Rock based on RQD

Rock Quality Designation (RQD)	Rock Quality
20	Very Poor

Table- III: Characterization of Pare Rock based on Terzaghi's Rock Load Theory

RQD (%)	Rock class	Rock Condition	Rock load (Hp)	Remarks
20	VI	Crushed	(0.6–1.10) (B + Ht) = 1(7.5 + 6.47) = 13.97	Considerable side pressure. Softening effects of seepage towards bottom of tunnel

B=tunnel span in meters; Ht = height of the opening in meters; and Hp= height of the loosened rock mass above tunnel crown developing load

Table- IV: Characterization of Pare Rock based on RSR System

Parameter A			Parameter B			Parameter C			Total RSR (A+B+C)
Rock type origin	*Rock Hardness*	*Geological Structure*	*Joint spacing (inch)*	*Joint orientation (Dip /Direction)*	*Direction of Tunnel drive*	*Overall Rock mass quality due to Parameter A and B*	*Joint Condition*	*Amount of water flow (gallons/min/m)*	
Sedimentary	Soft	Moderately to highly faulted	6 to 48	206°/72°	23°	40	Poor	6 – 33 gpm	49
Basic Rock Type		**Rating**	**Rating**				**Rating**		
IV		8	32				9		

Table- V: Characterization of Pare Rock based on RMR System

Tunnel Chainage (m)	UCS	RQD	Spacing	Condition of discontinuity	Groundwater	RMR basic	Orientation	RMR	Comment
1198.7	1	3	15	10	4	33	-2	31	Poor
	2	3	10	10	4	29	-2	27	

Table- VI: Characterization of Pare Rock based on Q System

Tunnel Chainage (m)	RQD_{min}	J_n	J_r	J_a	J_w	SRF	Q	Comment
1198.7	20	6	1	1.5	1	2.5	0.8889	Very Poor

Jn = joint set number, Jr = joint roughness number for critically oriented joint set, Ja = joint alteration number for critically oriented joint set, Jw = joint water reduction factor, SRF = stress reduction factor

Likewise, starting from chainage 1165.00m to 1265.10m of the Pare headrace tunnel, characterization was done, based on the geological mapping during actual tunnel excavation. It is found that from chainage 1165.00m to 1198.70m, the rock falls under "poor"categorywith RMR ranging from 25 – 40 and from chainage 1198.7m to 1265.10m, the rock falls under "very poor" category with RMR ranging from 18 – 22.

Whereas in Q-system, the rock falls under "poor" category throughout the length with Q value ranging from 0.2 – 1.33.

Retrieval Number: F9575038620/2020©BEIESP
DOI: 10.35940/ijrte.F9575.038620
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

IV. SUPPORT DESIGN

A detailed design of the support system for the Pare HRT is carried out, based on Q value and is presented in sub-section A and B, and the support systems recommended by various classification system is discussed in sub-section C together with the design analysis performed in this paper and the supports system actually provided at the site.

A. Methodology

As mentioned earlier, the rock comes under poor quality throughout the length with Q ranging from 0.2 – 1.33, and hence the design will be same throughout the considered length of the HRT. So, an average rock mass quality of $(Q_{max} x Q_{min})^{1/2}$ is assumed in the design calculations. As ultimate support pressure is related to rock mass quality, an empirical correlation was proposed by Singh et al. (1992) [2] for a time period of 100 years after the installation of supports:

$$p_{ult} = \frac{0.2}{j_r} . Q^{-1/3} . f . f' \quad (4)$$

Where,
p_{ult}= ultimate support pressure in MPa;
Q = rock mass quality;
f = correction factor for overburden = 1+ (H-320)/800≥ 1=1;
f' = correction factor for tunnel closure = 2 as J_r/J_a = 0.16< 0.5 (for squeezing condition);
H = overburden above crown or tunnel depth below ground level in meters = 200m.
Support Pressure is obtained using (4), which is taken into consideration while designing its support system taking the help of NATM. Also wall support pressure is calculated using (4) putting Q = 12.5 Q, as this support pressure is very important in case of squeezing rock condition.
For design of supports, bolt length, bolt diameter, shotcrete thickness, shear strength of shotcrete are the most vital component, from which we can check its support capacity.

Bolt Length, l_b= 2+(0.15 B or H/ESR) m (5)
Anchor Length, l_a= 0.40 B/ ESR m *(for Roof)* (6a)
l_a= 0.35 H/ESR m*(for Walls)* (6b)

Where, B = width of excavation in meter= 7.5m, H = height of excavation in meter = 6.5m, ESR = excavation support ratio = 1.6 for water tunnel as in *Barton, 2008*.

Thickness of Steel Fibre Reinforced Shotcrete lining,

$$t_{fsc} = \frac{p_{roof} . B . F_{fsc}}{2 q_{fsc}} \quad (7)$$

Where, p_{roof} = ultimate roof/wall support pressure, B = size of opening, F_{fsc}= mobilization factor of shotcrete = 0.6±0.05, q_{fsc}= shear strength of shotcrete = 600t/m^2

Singh et al. (1995) [14], *Singh and Goel* (2011) [2] and IS 15026 [15] are used to check for the total support pressure and are presented in the following sub-sections:

$$u + p_{roof/wall} = p_{sc} + p_{bolt} + p_{gt} \quad (8)$$

Where, u = seepage water pressure;
p_{roof}= roof support pressure ;
p_{sc} = capacity of SFRS (t/m^2);
p_{bolt} = capacity of rock bolts (t/m^2);
p_{gt} = capacity of grouted arch/rock column (t/m^2);

$$p_{sc} = \frac{2 . q_{fsc} . t_{fsc}}{B . F_{fsc}} \quad (9)$$

Where, p_{sc} = capacity of SFRS lining (t/m2);
q_{fsc} = shear strength of SFRS (t/m^2);
t_{fsc}= thickness of SFRS in mm;
B = size of opening;
F_{fsc}= mobilization factor for shotcrete = 0.6 ± 0.05;

$$p_{bolt} = \frac{2 . q_{crm} . l' Sin\theta}{B . F_s} \quad (10)$$

Where, p_{bolt} = capacity of rock bolt (t/m^2);
q_{crm} = uniaxial compressive strength (UCS) of reinforced rock mass(t/m^2);
l'= thickness of reinforced rock arch/rock column;
B = size of opening;
F_s = mobilization factor for rock bolts= 3.25 x $(p_{roof})^{0.1}$;
SinΘ = 1.3.B$^{-0.16}$;

$$q_{crm} = [\frac{P_{bolt}}{S_{bolt}^2} - u][\frac{1 + Sin\phi_j}{1 - Sin\phi_j}] \quad (11)$$

$\tan\phi_j = J_r/J_a$
=> ϕ_j= 33.69
l' = l_{bolt}- FAL/2 -S_{bolt}/4 + S_{rock};

Where, l = length of bolt
= 6 m for roof and 7m for walls,
P_{bolt}= Tension in bolt;
FAL = fixed anchor length=100 x Diameter of Anchor bar,
S_{bolt} = spacing of bolt;
S_{rock} = average spacing of joints;
u = seepage pressure in the rock mass;
J_r = joint roughness number;
J_a= joint alteration number.

B. Results and Discussion

The following Table VII shows the values obtained from (4), (5), (6a), (6b) and (7).

Table VII: Calculated results of Components of Support System

$Q_{avg} \approx Q$	Ultimate SupportPressure, p_{ult}(t/m^2)	Wall Support Pressure, (t/m^2)	Bolt Length l_b(m)	Anchor Length, l_a		Thickness of Shotcrete lining, t_{fsc}(mm)
				Roof (m)	Wall (m)	
0.52	50.98	37.42	2.73	1.95	1.42	191.2

But the value of length of bolt and thickness that New Austrian Tunneling Method (NATM)[13] proposed is 5-7m and 150-200mm respectively. Hence a set oftrials are done selecting different values of bolt length and thickness of concrete lining within the range. The final dimensions which give a safe design with respect to ultimate tunnel support pressure are presented in Table VIII with the help of (8), (9), (10) and (11).

Table- VIII: Analysis of Support Capacities

U, t/m^2	$p_{roof/wall}$, t/m^2	U + p_{roof}, t/m^2	B, m	q_{fsc}, t/m^2	t_{fsc}, mm	F_{fsc}	S_{bolt}, m	S_{rock}, m	P_{bolt}, ton	q_{crm}, t/m^2	l', m	F_s	SinΘ	p_{sc}, t/m^2	p_{bolt}, t/m^2	p_{gt}, t/m^2	p_{sc}, + p_{bolt}+ p_{gt}, t/m^2
5	50.98	55.98	7.5	600	160	0.64	0.8	0.11	10	37.0 95	4.66	3.2	0.94	42.67	13.6	0	56.27

C. Support Systems Suggested by Various Methods

There is various support category recommendation for tunnel in many of the Rock Mass Classification System as mentioned earlier. In this paper, a study is being done for support measures using Terzaghi's Rock Load Theory, Classification System of Stini and Lauffer, Deere's Rock Quality Designation (RQD) Classification System, Rock Structure Rating (RSR) Classification System, Rock Mass Rating (RMR) system of Bieniawski and Rock mass quality (Q) system of Barton et al. as shown in Table IX.

Table-IX: Support Systems based on Various Classification Systems for Pare HRT rock

Terzaghi's Rock Load Theory	Value of Rock Load Factor	13.97 (from Table III)
	Value of RQD	20
	Support Measure	Medium to heavy circular steel sets with spacing of 0.6 to 1.2m, rock bolts with a spacing of 1.2 to 1.8 m and considerable mesh and straps required together with 15cm shotcrete layer for the Drilling and blasting construction method as given in *Terzaghi, 1946* [7]
Classification system of Stini and Lauffer	Value of Active Span	7.5 m
	Stand-up time	1 day as per the chart given by *Lauffer, 1988* [17]
Rock Quality Designation (RQD)	Value of RQD	20, Very poor as mentioned in Table II
	Support Measure	Heavy circular steel sets with 0.6 m centre to centre having a Rock load of 2.0 to 2.8B , rock bolts pattern of 0.9 m centre to centre to centre and shotcrete layer of thickness 150mm or more, combined with medium to heavy sets as per *Deere, 1969* [18]
Rock Mass Rating (RMR) system	Total RMR value	31 and 27 (from Table V)
	Support Measure	Excavation recommended to be multiple drifts of 0.5-1.5 m advancement in top heading with installation of support concurrently with excavation and shotcreting is to be done as soon as possible after blasting. Recommended support should be Systematic bolts of 20mm diameter and 5-6 m long, spaced 1-1.5 m in crown and walls; Shotcrete layer of thickness 150-200 mm in crown and 150 mm in sides; and steel sets containing medium to heavy ribs spaced 0.75 m with steel lagging and forepoling if requiredas per *Bieniawski 1989*[20]
Rock Mass Quality (Q) system	Value of Q	0.889 (from Table VI)

	Support Measure based on the design performed	Steel fibre reinforced Shotcrete of thickness 160 mm, having shear strength of 600t/m^2, bolt length of 5m having diameter 25mm with a spacing of 0.8m should be provided
Actually provided on Site	Support Measures	Initial layer of concrete on face and crown, single layer of wiremesh (100mmX100mmX5mm) with shotcrete of 100mm thickness, Bolting with 16mm diameter tie rods, ISMB200 steel Rib with 1000mm c/c, Backfill Rib spacing with shotcrete. 32mm dia. 4000mm long forepoles @ 250mm C/C in the crown wherever required.
Rock Structure Rating (RSR) system	Total RSR value	49 (from Table IV)
	Support Measure	3 inches of shotcrete, 1 inch diameter rock bolts spaced at 3 ft centre to centre and the support could be provided by 6 H 20 steel sets (6 inch deep wide flange H section weighing 20 lb per foot) spaced 4 feet apart [19] as per *Wickham et al, 1974*.

V. CONCLUSION

Various parameters to characterize Pare Rock Mass of the Upper-Siwalik Sub-Group of the Sub-Himalayan Range have been determined and presented in this paper. These parameters have also been used to design the support system for the HRT for Pare Rock Mass. Based on the study, following conclusions are drawn.

- Excavation of the HRT reveals that thePare Rock mass is predominantly medium grained, salt pepper textured, soft, friable, grayish,weak to very weak, moderately to highly jointed sandstone with seepage facewith occasional alternate lenses of pebbly sandstone and carbonaceous shale.
- RQD obtained from volumetric joint count *(Palmstrom, 2005)* gives a very high value, above 90%, whereas, that obtained by core logging as per *Deere, 1988*gives an average RQD of 20.
- Based on the average RQD value, Pare Rock Mass Quality falls under "very poor" category. As per Terzaghi'srock load factorof 13.97, rock class is VI. Following Rock Structure Rating of 49, basic rock type is IV. As per the RMR value, Pare rock mass may be termed as "Poor" to "Very Poor" and as per the Q value, the same falls under "Very Poor" category.
- For an active span of 7.5m of the opening, the stand-up time of the rock mass is 1 day.
- Terzaghi's Rock Load Factor suggests the thickness of the shotcrete lining for the HRT as 150mm. Deere(1969) based on RQD, Bieniawski(1989) Rock Mass Rating and Barton's Q value indicates the thickness of the shotcrete lining of the HRT to be above 150mm. The thickness of the shotcrete lining is arrived at a value of 160mm, following provisions of IS 15026 (2002). However, in practice a thickness of 100mm of the shotcrete lining is found to behave satisfactorily for most of the length of the HRT except attaining squeezing condition in a few locations. However, the same calculated as per Rock Structure Rating (RSR) is only 75mm and may be termed as inadequate.
- RSR is slightly on the higher side so far rock bolt diameters is concerned, but on the lower side when it comes to steel rib size.

ACKNOWLEDGMENT

This work is the result of a research project sponsored by NEEPCO Ltd. We sincerely acknowledge NEEPCO Ltd. For providing us the various geological as well as geotechnical data of Pare rock mass, which was necessary for carrying out the present work.

REFERENCES

1. H. Dev and S.K. Sharma, Eds., *Monograph On Rock Mass Classification Systems and Applications.* New Delhi, India: Central Soil and Materials Research Station, 2011. [Online]. Available: http://csmrs.gov.in.
2. B. Singh and R.K. Goel, "*Engineering Rock Mass Classification: Tunneling, Foundations, and Landslides*," Elseiver, Edinburgh, London, New York Oxford, Philadelphia St Louis Sydney Toronto, 2011, pp. 1-113.
3. D.U. Deere. and D.W. Deere, "The rock quality designation (RQD) index in practice in Rock classification systems for engineering purposes,"*ASTM,* vol. 984,pp. 91-101,1988.
4. A. Palmstrom, "Measurements of and correlations between block size and rock quality designation (RQD)," *Tunn. Undergr. Sp. Tech*., vol. 20, pp. 362-377, 2005.
5. D. U. Deere,"Rock quality designation (RQD) after 20 years*", U.S. Army Corps Engrs. Contract Report GL-89-1.* Vicksburg, MS: Waterways Experimental Station, 1989.
6. D.U. Deere,"Geological considerations, rock mechanics in engineering practice,*" In R. G. Stagg & D. C. Zienkiewicz* (Eds.). New York: Wiley, pp. 1–20, 1968.
7. K. Terzaghi, *Introduction to tunnel geology. In R. V. Proctor & T. L. White (Eds.),* Rock tunnelling with steel supports, Youngstown, OH: Commercial Shearing & Stamping Co., 1946,pp. 271.
8. G. E. Wickham, H. R. Tiedmann and E. H. Skinner, "Support determination based on geologic predictions,"*Proc. 1st Rapid Excavation and Tunn. Conf.,* Chicago, Vol. 1, 1972, pp. 43-64.
9. Z.T. Bieniawski,"*The geomechanics classification in rock engineering application,* InProceedings of the 4th Congress of the International Society for Rock Mechanics," ISRM Montreux, September 2–8, 1979, Vol. 2, pp. 41–48.
10. Z.T. Bieniawski, In J. A. Hudson (Ed.), "*Classification of rock masses for engineering: The RMR system and future trends, comprehensive rock engineering*," New York: Pergamon Press, 1993, Vol. 3, pp. 553–574
11. N. Barton, R. Lien,& J. Lunde, "Engineering classification of rock masses for the design of tunnel support,"Norwegian Geotechnical Institute, 1974, NGI Publication No. 106, pp. 48.
12. N. Barton,"Some new Q-value correlations to assist in site characterisation and tunnel design," Int J Rock Mech Min, pp. 185–216, 2002.
13. A. Palmstrom and D. Stipendiat, *The New Austrian Tunnelling Method (NATM)*, Norges Geotekniske Institutt Oslo, 1993, pp. 31.16.
14. B.Singh, M.N. Viladkar, and N.K. Samadhiya, "A Semi-Empirical Method of the Design of Support Systems in Underground Openings,"*Tunn. Undergr. Sp. Tech*., pp. 375-383, 1995.

15. IS 15026 (2002) Tunnelling Methods in Rock Masses—Guidelines. Bureau of Indian Standards, New Delhi, pp. 26.
16. A.K. Naithani, L.G. Singh, and P. Jain, *"Rock Mass Characterization and Support Design for Underground Additional Surge Pool Cavern—A Case Study," India*. Geomaterials, 2017, pp. 64-82.
17. H. Lauffer,*ZurGebirgsklassifizierung bei Frasvortrieben*, Felsbau, 1988, pp. 137–149.
18. D.U. Deere, R.B. Peck, J.E. Monsees and Schmidt, "*Design of tunnel; liners and support systems"*, Report prepared by University of Illinois Urbana, for the office of High Speed Ground Transportation, NTIS Publication PB, 1969, pp. 183-799.
19. G.E. Wickham and H.R. Tiedmann, "Ground support prediction model - RSR Concept,"*Proc. 2nd Rapid Excavation and Tunnelling Conf.*, Chicago, Vol. 1, 1974, pp. 691-707.
20. Z.T. Bieniawski, *"Engineering rock mass classifications,"* John Wiley and Sons, New York, 1989, pp. 251.

AUTHORS PROFILE

Pragati Goswami has completed B.Tech in Civil Engineering from Assam Science and Technology University (ASTU), Guwahati. She is currently pursuing M.Tech. in Geotechnical Engineering under ASTU from Assam Engineering College, Guwahati. Her areas of interest are Geotechnical Engineering, Rock Mechanics. Her recent publication is on *"Stability of Slopes for Dam Excavation by Slope Mass Rating in the Pare Hydroelectric Project"* in the journal named International Journal of Engineering Research & Technology (IJERT).

Dr. Diganta Goswami is currently working as Associate Professor in Department of Civil Engineering in Assam Engineering College, Guwahati. He obtained his Ph. D. degree in Civil Engineering from IIT, Roorkee. His areas of research include Geotechnical Engineering, Finite Element Analysis, Tunnels and other river valley project, Foundation Analysis and Design. He has published more than 30 articles in reputed journals and handled many government and private funded projects in India.His recent publication is on *"Stability of Slopes for Dam Excavation by Slope Mass Rating in the Pare Hydroelectric Project"* in the journal named International Journal of Engineering Research & Technology (IJERT).

Ranjeet Bahadur Singh isworking with NTPC Limited as a Deputy General Manager (Civil). He has completed his MSc. Engineering in Water Resources from National Institute of Technology (Patna). He has had the privilege of contributing in the construction work of Tala Hydroelectric Project Authority (THPA), an autonomous entity set up by the Government of India in collaboration with the Royal Government of Bhutan. He was also involved and has overseen the construction of the Lohari Nagpala Hydro Electric Power Project (LPHPP), a flagship project of NTPC Limited which is one of the most challenging terrains of the Upper Ganga Basin.His recent publication is on *"Stability of Slopes for Dam Excavation by Slope Mass Rating in the Pare Hydroelectric Project"* in the journal named International Journal of Engineering Research & Technology (IJERT).

Pawan Kumar Singh has completed B.E in Civil Engineering from Jorhat Engineering College, Jorhat and M.E. in Geotechnical Engineering from Assam Engineering College, Guwahati. He is currently pursuing Ph.D. under Gauhati University, Guwahati. His areas of interest are Geotechnical Engineering. Slope Stability, Rock Mechanics.His recent publication is on *"Stability of Slopes for Dam Excavation by Slope Mass Rating in the Pare Hydroelectric Project"* in the journal named International Journal of Engineering Research & Technology (IJERT).

Sylvia Kashyap has completed B.Tech in Civil Engineering from Assam Science and Technology University (ASTU), Guwahati. She is currently pursuing M.Tech. in Geotechnical Engineering under ASTU from Assam Engineering College, Guwahati. Her areas of interest are Geotechnical Engineering, Rock Mechanics.Her recent publication is on *"Stability of Slopes for Dam Excavation by Slope Mass Rating in the Pare Hydroelectric Project"* in the journal named International Journal of Engineering Research & Technology (IJERT).